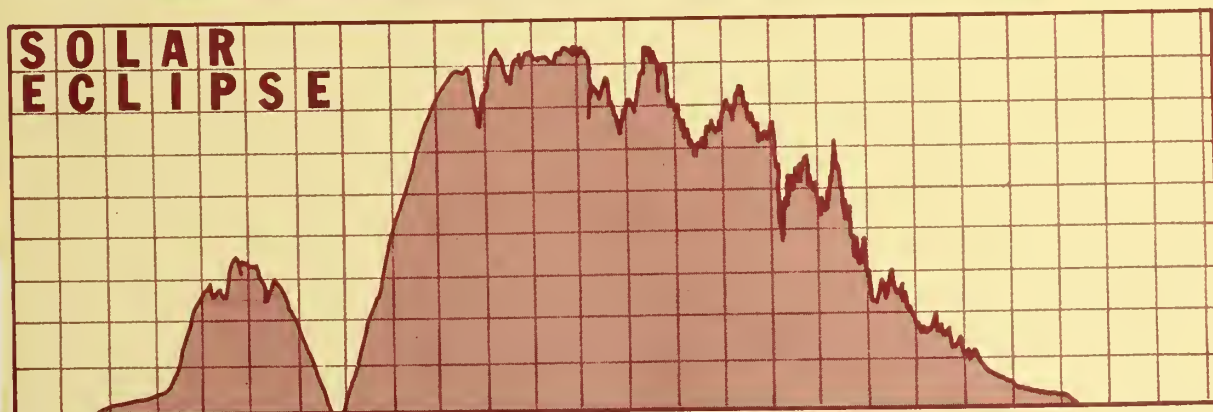
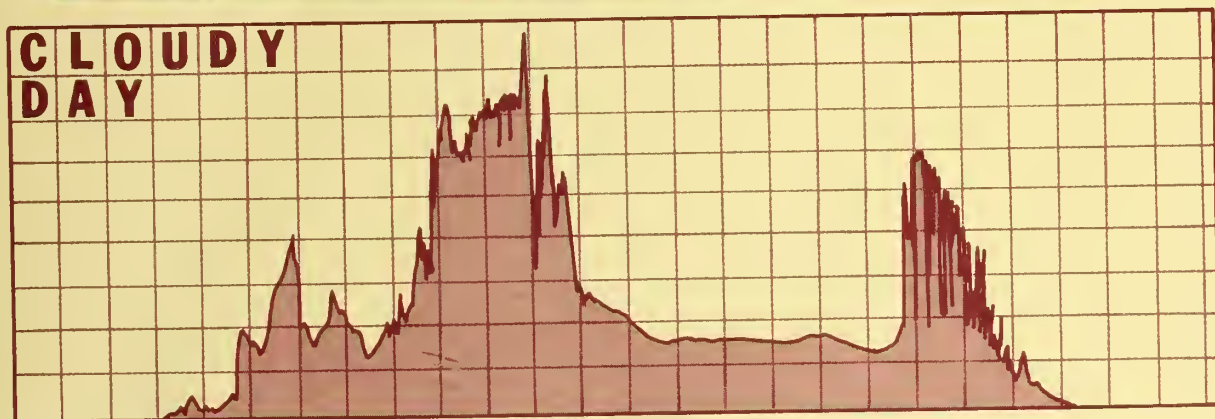
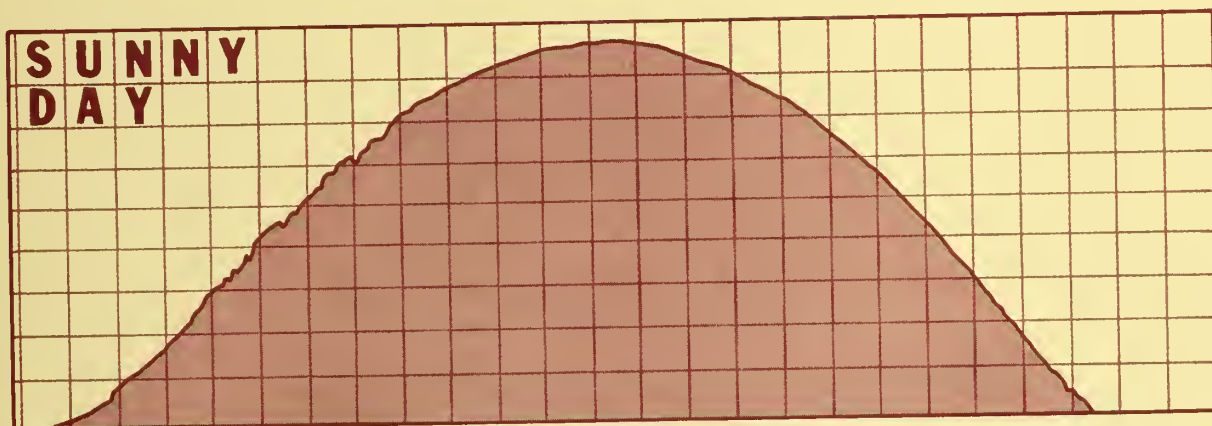



# Montana Solar Data Manual

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# **MONTANA SOLAR DATA MANUAL**

compiled by

Charless W. Fowlkes, PhD, PE

## **FOWLKES ENGINEERING**

31 Gardner Park Drive  
Bozeman, MT 59715

published by

Montana Department of Natural Resources and Conservation  
Energy Division  
Capitol Station  
Helena, MT 59620

October 1985

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## **NOTICE**

This report was prepared as an account of work sponsored by the Energy Division of the Montana Department of Natural Resources and Conservation through the Alternative Renewable Energy Resources Program. Neither the State of Montana nor the Department, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe on privately owned rights.

## **COVER**

Reproduced on the cover are strip chart records of Montana solar radiation. The upper chart illustrates a clear day record, and the center chart was taken on a partially cloudy day. The lower chart records the total eclipse on February 26, 1979.

The solar radiation data base contained in this edition is a summary of 50,126 daily strip charts recorded at thirty Montana stations between January 1977 and December 1982.

## ACKNOWLEDGMENTS

The author is grateful to many people who have contributed to the Montana Solar Data Manual. The Montana State Legislature is acknowledged for its support of alternative energy. The staff of the Energy Division of the Department of Natural Resources and Conservation (DNRC) is acknowledged for its support of this solar energy measurement program from 1977 through 1982. Mike Chapman, DNRC, and Grant Vincent, Bonneville Power Administration (BPA), are acknowledged for their work in a program for archiving the entire Montana solar radiation data base and preparing this summary document.

The volunteered assistance of over thirty Montana high school science teachers in maintaining the solar measurement instruments was crucial to the success of this program. Their names are listed in Appendix 3, and their many contributions are gratefully acknowledged.

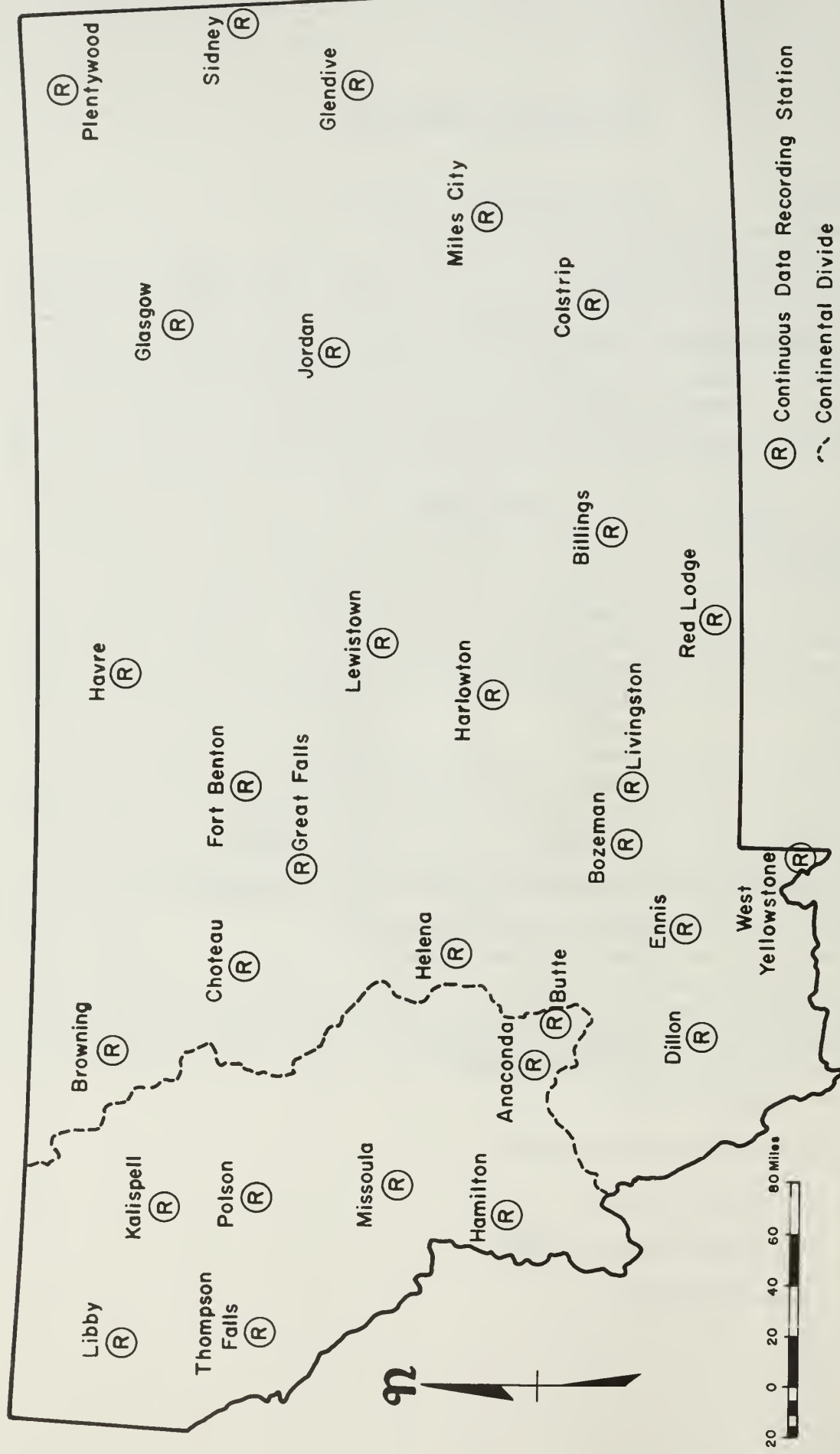
Several members of the staff at Fowlkes Engineering have contributed to the solar measurement program. Sharon Kleingartner is acknowledged for her central role in entering over 50,000 days of solar radiation data into the computer for processing. Numerous computer programs to process and verify that data were written by Carlos Lozano, Kellee Crisafulli, and Ross Nelson. Terri Ferguson, Pat Sullivan, and Jodi Martinson have contributed to data management and preparing earlier data manuals and publications. Jack Mefford is acknowledged for his recent contributions including reviewing the entire solar data base for errors, assembling archive data tapes, and writing computer programs to output the summary data tables in the Montana Solar Data Manual.

The quality of the solar measurement program has benefited from the guidance of several expert consultants. John Yellott has provided continuing advice concerning the accuracy of our measuring instruments. Douglas Hoyt (National Oceanic and Atmospheric Administration) provided computer codes to calculate theoretical clear-day solar radiation to improve the accuracy of the data. Joe Caprio (Montana State University) provided climatological data from his extensive files. S. Klein (University of Wisconsin) provided the tilt-correction factors used in this manual. Roland Hulstrom (Solar Energy Research Institute), Paul Berdahl (Lawrence Berkeley Laboratory), Ray Bahm, and Mark McKinstry have given guidance on various aspects of the program.

We have received many comments about previous editions of the Montana Solar Data Manual from engineers, architects, homeowners, solar enthusiasts, government officials, scientists, and solar experts. We gratefully acknowledge this broad interest and support and hope that new data in the present document will be useful and will advance the utilization of solar energy in Montana.

# TABLE OF CONTENTS

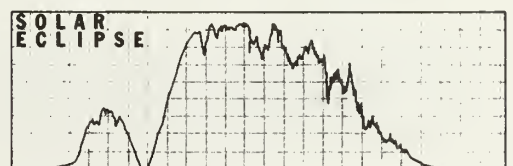
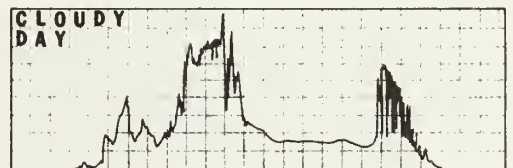
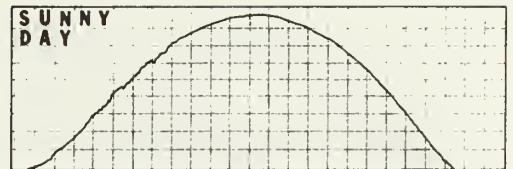
<b>1. INTRODUCTION . . . . .</b>	<b>1</b>
1.1 Background of the Solar Insolation Measurement, Montana (SIMM) Program. . . . .	3
1.2 Guide to the Solar Data Tables . . . . .	3
<b>2. UNDERSTANDING AND USING THE DATA TABLES . . . . .</b>	<b>5</b>
2.1 Table 1. Average Solar Radiation on Tilted Surfaces Facing South . . . . .	7
2.2 Table 2. Average Utilizability . . . . .	8
2.3 Table 3. Average Net Solar Gain of South-Facing Windows. . . . .	9
2.4 Table 4. Climatological Data . . . . .	10
<b>3. SOLAR DATA TABLES FOR THIRTY MONTANA SITES . . . . .</b>	<b>11</b>
(Alphabetically by Site)	
Anaconda	Glasgow
Billings	Glendive
Bozeman	Great Falls
Browning	Hamilton
Butte	Harlowton
Choteau	Havre
Colstrip	Helena
Dillon	Jordan
Ennis	Kalispell
Fort Benton	Lewistown
	Libby
	Livingston
	Miles City
	Missoula
	Plentywood
	Polson
	Red Lodge
	Sidney
	Thompson Falls
	West Yellowstone
<b>4. GUIDELINES FOR SOLAR HEATING DESIGN AND PERFORMANCE ESTIMATION . . . . .</b>	<b>43</b>
4.1 Some Basic Solar Heating System Design Considerations . . . . .	45
4.2 Active Solar Heating System Performance Estimation. . . . .	45
4.3 Passive Solar Performance Estimation. . . . .	47
4.4 Economic Considerations . . . . .	50
4.5 Correction Factors for East or West Orientations . . . . .	50
4.6 Solar Position and Clear Day Solar Radiation . . . . .	50
4.7 Other Design Resources. . . . .	54
<b>APPENDIX 1. Source Data, Site Documentation . . . . .</b>	<b>55</b>
<b>APPENDIX 2. Accuracy of Solar Data . . . . .</b>	<b>63</b>
<b>APPENDIX 3. List of Site Volunteers, 1977-1982 . . . . .</b>	<b>71</b>
<b>APPENDIX 4. Conversion Identities . . . . .</b>	<b>75</b>



(R) Continuous Data Recording Station  
 --- Continental Divide

# SOLAR RADIATION NETWORK

# INTRODUCTION





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## **1.1 Background of the Solar Insolation Measurement, Montana (SIMM) Program**

Early in 1977, the SIMM program was initiated by Fowlkes Engineering under a grant from the Renewable Alternative Energy Resources Program of the Montana Department of Natural Resources and Conservation (DNRC). Twenty instruments to measure solar radiation were sited across Montana during 1977, and an additional ten instruments were sited early in 1978 (see map on p. IV ). The program goal was to measure the solar resource within Montana to provide data for the systematic analysis and development of equipment to use solar energy.

All measurements of solar radiation were made on south-facing surfaces tilted 60 degrees from horizontal, because this orientation simulates the orientation of a solar collector. The front cover of the Montana Solar Data Manual shows three examples of daily solar radiation records; 50,126 days of valid data were collected between 1977 and 1982. A summary of six years of solar measurements is presented in this manual.

During 1974, DNRC and the Bonneville Power Administration (BPA) jointly sponsored a project to archive the entire data base on a 9-track computer tape and to document the details of the instrumentation at each site. The data on this tape include the average solar intensity during each half-hour at each of the thirty Montana sites for six years. The Montana Solar Data Archive Document, a companion to the data tape, gives details of the sensor mounting, shading, and maintenance records for each of the thirty sites.

Copies of this document are available for researchers who may want to use the data for solar energy studies, agricultural, or forestry research, etc. A sample of the site documentation (taken from the Archive Document) is given in Appendix 1 of this manual. Readers wanting more details of this type should get a copy of the Archive Document and the Montana Solar Data Tape.

Another task of the DNRC/BPA project was to produce this summary document, the Montana Solar Data Manual (MSDM), to make the solar radiation data available for use by engineers, architects, solar designers, and others who do not need the detailed half-hourly data. Monthly average data are adequate for designing and estimating the performance of most solar heating equipment. The solar data in the MSDM are presented in the form of monthly average values spanning the entire six-year period.

The roots of any data document are the accuracy and range of the data (see Appendix 2). We believe that the six-year sample of data can be considered "typical" for the purposes of most solar energy design tasks. Most of the sites have no other source of solar radiation data.

## **1.2 Guide to the Solar Data Tables**

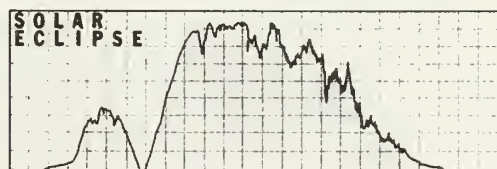
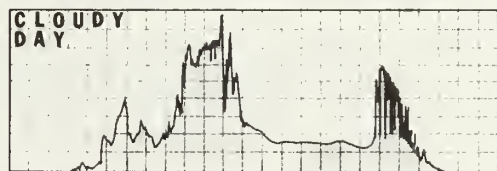
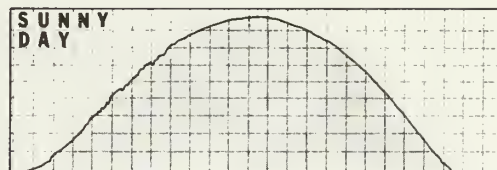
The solar data (in Section 3) is arranged alphabetically by site; the data from each site have been condensed into a single page. The user of this manual should pick the data site nearest to the location for which he wants data. Since there are thirty sites, the user should be able to find a data site within sixty miles of any location in Montana. Differences in monthly average solar data between adjacent sites are typically quite small (unless the sites are on opposite sides of a mountain range).

A few sites had significant losses of data due to equipment or communication failures. The user can identify these sites—each solar data table also includes the actual number of days of data used to compile the table. Generally, the greater the number of data days, the better the quality of data. For example, Thompson Falls had 999 days of valid data; Missoula, Polson, and Kalispell each had about 2,000 valid data days.

The user needing solar data for that part of Montana should favor data from those sites having a stronger data base.

The tables in this edition use "conventional" units because users of previous editions had trouble with metric units. British thermal units (Btus) are used for energy, square feet for area, and degrees Fahrenheit for temperature. To fit the monthly average data into the tables, units of thousands of Btus are sometimes used, thus the number 21.6 may represent 21,600 Btus. The units in each table are given in the heading.

# UNDERSTANDING AND USING THE DATA TABLES





## 2.1 Table 1. Average Solar Radiation on Tilted Surfaces Facing South

The site name appears above the tables, along with the latitude, longitude, and elevation of the site. The first data table lists the average monthly total solar radiation, in thousands of Btus per square foot, that will reach a tilted solar collector facing true south. Tilt is measured up from the horizontal in degrees—horizontal is 0 degrees, vertical is 90 degrees, etc.

The middle row of table 1 (Tilt = 60 degrees) is marked with "\*" denoting measured data. This row of data is based on the Archive Data Tape, which records the solar radiation measured during each half-hour of every day during the six-year period.

The procedure used was to scan the Archive Data Tape and pick out all days with error-free data in a particular month, for instance, January. The half-hour solar data were first integrated to form a daily total solar radiation value. All valid data days for January over the six-year period were then used to calculate a daily average solar radiation for January. This number was multiplied by 31 to produce a monthly total, which appears in the table under JAN at Tilt = 60 degrees.

The number of valid data days used to form the average monthly total is shown as the last line of table 1. The number of valid data days will vary from month to month and from site to site. Some sites were instrumented for five years and some for six years. The reliability of the instruments and the amount of attention given to the instruments by the volunteers varied (see Appendix 1 and 2 for more information). "Data days" can be used to judge the strength of the data at a particular site. The data from "stronger" adjacent sites may be used to supplement data from "weaker" sites.

The measured, 60-degree data are appropriate for the design of active solar collectors to be used for space heating in Montana during the winter. Passive solar windows are usually vertical (90 degrees); collectors for heating domestic water are usually tilted to around 45 degrees; many roofs are sloped at angles of about 30 degrees. To make table 1 usable for these and other tilts, the table was expanded, using calculated values.

Technical literature on solar engineering contains several rules or empirical equations developed to convert solar radiation measured at one particular tilt to the solar radiation expected on a differing tilt. Recent work at the Solar Energy Laboratory of the University of Wisconsin under Dr. S. Klein has produced accurate tilt correction rules. Dr. Klein ran a number of computer programs to implement these rules for sites in Montana. The resulting tilt-correction factors were applied to the measured 60-degree data to provide estimates of solar radiation on tilts varying from 30 degrees up to 90 degrees. These values are given in table 1.

These calculated data have more uncertainty than the measured data. In the researcher's judgment, the calculated data are adequate for design purposes and represent the best data available at this time.

The last column of table 1, under YEAR, contains the yearly total solar radiation at each tilt in thousands of Btus per square foot of area. The last entry in the last row (data days) is the total number of valid, measured data days for that site during the entire SIMM program.

---

**Example problem:** "How much solar energy 'falls on' a south-facing roof, having a tilt of 30 degrees and an area of 600 square feet, in Anaconda during March?"

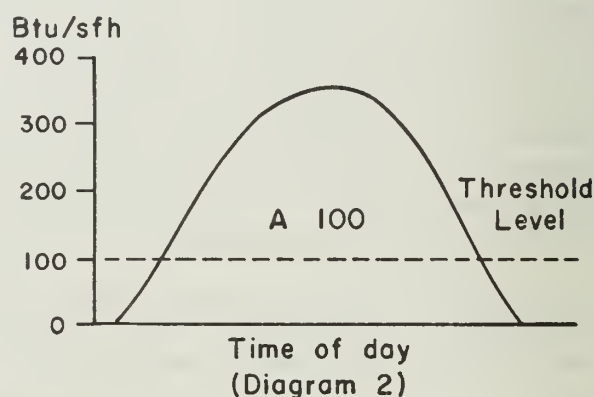
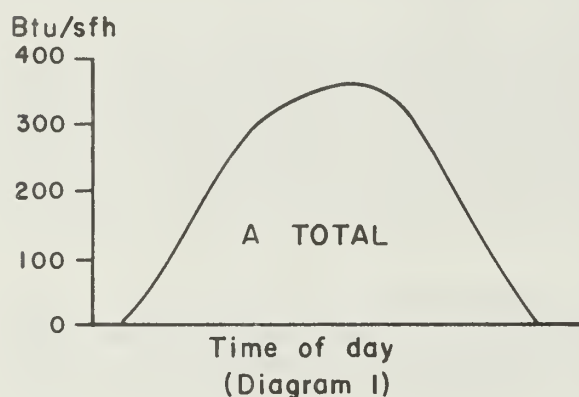
**Solution:**

- 1) Use the data tables for Anaconda and locate table 1
- 2) At Tilt = 30, under MAR, read 39.7 kBtus/sq ft/month
- 3) Answer =  $600 \times 39,700 = 23,820,000$  Btus

## 2.2 Table 2. Average Utilizability

Solar collectors receive thermal energy from the solar radiation “flowing into” them. Since the solar collectors are warmer than the surrounding air, some portion of this thermal energy will necessarily “flow out” as a loss. You might imagine this situation as similar to pouring water into a bucket that has a hole in it. If the bucket leaks one gallon per minute, the flow into the bucket must exceed a “threshold” of one gallon per minute to eventually fill the bucket.

The flow of solar energy varies throughout each day. The curves on the cover of this manual show three specific examples of the variation in solar flux. Diagram 1 depicts the variation in solar flux on a clear day. The area under this curve represents the total solar energy. This value can be calculated from our Archive Data Tape by adding up the half-hour average solar flux for any particular day. This procedure was used for table 1.



**Solar flux for one day showing graphic interpretation of total energy and energy above 100 Btus/sq ft/hr. Utilizability =  $A_{100}/A_{\text{total}}$ .**

Suppose we draw a threshold LEVEL line of 100 Btus/sq ft/hr on top of the solar flux curve, as shown in diagram 2. If we add up only the area between the threshold LEVEL and the solar flux curve, the result is an area we will call “A100”. We divide A100 by A total, multiply by 100 to express as a percent, and define this as “the percent utilizability” above a threshold of 100 Btus/sq ft/hr.

Assume on this day the total solar energy was 2,000 Btus/sq ft and the percent utilizability above a level of 100 Btus/sq ft/hr was 42 percent. If we had a solar collector that lost (or leaked) at a rate of 100 Btus/sq ft/hr, the (potentially) usable energy would be only 42 percent of 2,000, or 840 Btus/sq ft.

The balance between solar flux and losses is a fundamental physical parameter for predicting solar collector performance. Utilizability is a property of the solar data that can be used to implement design methods for solar collectors. To calculate the utilizability values presented in table 2, we scan each half-hour of each day of data in the Archive Data Tape and add up solar flux values that exceed three threshold levels—50, 100, and 200 Btus/sq ft/hr. These daily results are averaged during each month.

Table 2 presents a summary of monthly average utilizability above the thresholds, expressed as a percent of total energy. To use this table, first get the monthly total energy from table 1. Pick the utilizability for that month, for the threshold level you want from table 2. The utilizability times the monthly total divided by 100 is the “potentially usable energy” above that threshold.

**Example problem:** "How much solar radiation is available on a 90 degree surface, above a level of 50 Btus/sq ft/hr, in Great Falls during February?"

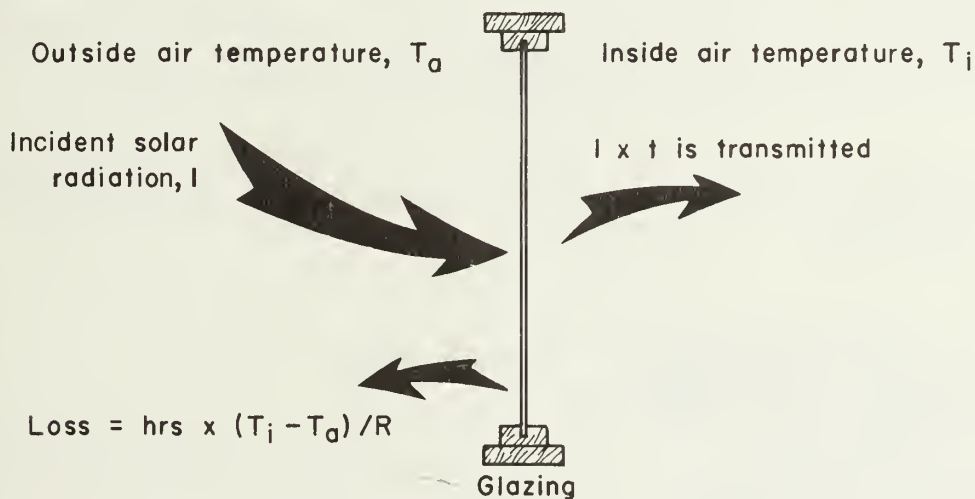
**Solution:**

- 1) Use Great Falls Data Tables in Section 3
- 2) From table 1, pick out total energy: 28,500 Btus/sq ft
- 3) From table 2, pick out utilizability: 65.8%
- 4) The answer:  $65.8 \times 28,500/100 = 18,753$  Btus/sq ft

## 2.3 Table 3. Average Net Solar Gain of South-facing Windows

In Montana there is considerable interest in using "passive solar" for heating buildings. (More discussion about the design of passive solar heating systems is included in Section 4.3 of this manual.) To assist the designer we have calculated the net solar gain of four window systems using our measured solar radiation data and long-term average climate data. The windows are assumed to be mounted in a vertical wall that faces due south.

Calculation of net solar gains is based on the thermal model depicted in the diagram shown below.



**Thermal Model of Window Used for Table 3**

Only part of the solar radiation striking the window will be transmitted into the living space; this characteristic of the glazing is called its transmittance ( $t$ ). If there is a temperature difference across the glazing, heat will flow from the warm side to the cooler side. Each glazing system has a characteristic resistance ( $R$ ), to heat flow. Typical values for optical transmittance and thermal resistance of various windows can be found in appropriate handbooks.

The four glazing systems we considered and their respective (nominal) values for transmittance and thermal resistance are shown in the table below. The actual transmissivity of a specific window at any time depends on the composition of the glass, its thickness, the angle of the sun's rays, how clean the window is, shading details such as curtains, window mounting, etc. Similarly, the real thermal resistance depends on current wind velocity, time of year, size of the air space in multiple glazings, etc. Recognizing these variations, we have tried to select average, effective values that will give representative net energy balances.

Window system	Transmissivity	Resistance (sq ft/hr-F/Btu)
Single pane	0.82	0.91
Double pane	0.71	1.2
Triple pane	0.60	2.56
Double pane + R-3	0.71	3.97 (eff)

The last glazing system "Double + R-3" assumes that the double-glazed window is covered during the nighttime (16 hours) with a movable insulation system having an additional thermal resistance of 3 sq ft/hr-F/Btu. The effective or daily average R of this system is 3.97. Section 4.3 discusses further practical issues of designing and using movable insulation systems.

The energy balance calculation for table 3 uses the monthly average solar radiation on a 90 degree surface multiplied by the appropriate transmissivity to calculate solar energy input. The inside temperature ( $T_i$ ) is assumed to be a constant 58 degrees F, and  $T_a$  is the monthly average ambient air temperature for the site. This temperature difference, multiplied by the hours in each month and divided by the appropriate R value, is used to calculate the monthly heat loss through the window. The net solar gain shown in table 3 is the solar input minus the heat loss. The units are thousands of Btus per square foot of glazing per month.

Some of the glazing systems, during midwinter, lose more heat through conduction than they gain from the solar radiation. The solar gains for these months are negative in table 3. The last column of the table, under YEAR, lists annual net energy gain in thousands of Btus per square foot of glazing.

---

**Example problem:** "What is the energy gain of a 20-square-foot, double-glazed window in Great Falls during November?"

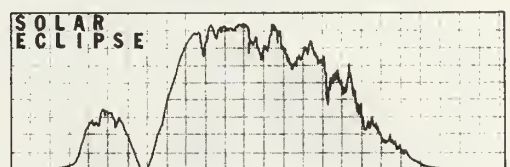
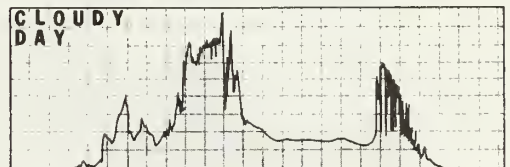
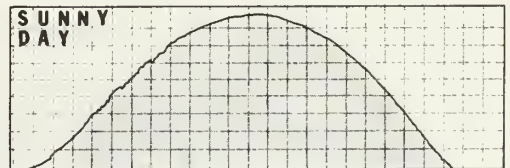
**Solution:**

- 1) Check the data tables for Great Falls
  - 2) Table 3: under NOV for "double pane," find 6.3 kBtus/sq ft
  - 3) Answer =  $20 \times 6,300 = 126,000$  Btus
- 

## 2.4 Table 4. Climatological Data

Table 4 shows selected long-term average climatological data, taken from National Weather Service records, that span a measurement period of forty years or more. Included are monthly average temperatures; mean daily, maximum daily, and minimum daily; monthly record high and record low. The average degree days (base 65 degrees F) are listed for each month. The last column of this table, under YEAR, shows annual averages of the temperatures and the annual total degree days.

# SOLAR DATA TABLES FOR THIRTY MONTANA SITES





# ANACONDA, MONTANA

Lat: 46.1°

Long: 113.0°

Elev: 5331 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1978-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	25.1	27.6	39.7	45.7	42.6	49.4	57.0	50.0	43.4	37.3	22.4	18.3	458
40	26.5	29.1	40.4	45.3	40.9	47.0	54.2	48.7	43.8	39.3	24.2	19.5	458
50	27.4	29.7	40.0	43.6	38.7	43.4	50.6	46.5	43.4	40.1	25.2	20.4	449
* 60	27.6	29.7	38.9	41.2	35.5	39.5	46.0	43.5	42.1	40.1	25.7	20.8	430
70	27.4	29.1	36.9	37.9	32.0	34.8	40.5	39.6	39.6	38.9	25.4	20.6	402
80	26.2	27.6	34.2	33.8	28.1	29.6	34.5	34.4	36.2	37.3	24.9	20.2	366
90	24.9	25.8	30.7	29.2	23.5	24.5	28.0	29.1	32.0	34.5	23.4	19.1	324
Data days	107	102	98	139	140	106	110	95	108	113	117	138	1373

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	64.1	63.8	64.2	63.1	56.8	58.8	63.8	64.5	67.3	69.4	62.9	58.3	63.4
100	42.2	41.0	41.6	39.4	33.3	34.7	40.5	41.1	44.6	47.7	40.5	34.6	40.4
200	14.0	14.0	15.1	12.1	8.6	7.8	11.0	11.5	15.0	17.7	12.3	8.0	12.4

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-17.0	-9.3	-6.4	1.4	3.5	10.3	21.0	20.7	15.5	9.4	-9.2	-18.8	21
Double Pane	-2.1	2.2	5.1	8.8	8.3	12.2	18.9	19.0	17.0	14.5	1.6	-4.7	100
Triple Pane	1.6	4.6	7.2	9.5	8.5	11.2	16.1	16.4	15.4	14.0	3.9	-.8	107
Double + R3	9.1	11.3	14.6	15.6	13.1	15.1	19.5	20.0	20.3	20.2	10.1	5.7	174

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	22.3	26.7	29.4	39.5	48.8	55.6	65.6	64.1	54.4	44.9	32.1	25.8	42.5
Daily Max	29.2	32.8	39.0	49.5	59.5	67.8	79.0	76.9	65.7	53.6	39.5	32.3	52.2
Daily Min	14.7	17.0	21.5	30.3	38.1	45.1	52.7	50.9	43.1	34.8	24.8	18.6	32.7
Extreme Max	54.0	58.0	67.0	84.0	90.0	95.0	99.0	100.0	92.0	82.0	71.0	59.0	79.4
Extreme Min	-30.0	-35.0	-18.0	-9.0	17.0	24.0	32.0	28.0	5.0	-8.0	-25.0	-29.0	-3.8
Degree Days	1324	1072	1104	765	502	294	72	112	344	623	987	1215	8414

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# BILLINGS, MONTANA

Lat: 45.8°

Long: 108.5°

Elev: 3117 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	26.6	29.5	43.9	48.7	49.1	55.1	57.9	56.8	50.7	39.1	27.9	21.2	506
40	29.5	31.5	45.2	48.3	47.4	52.4	55.1	55.4	51.2	41.3	30.6	23.6	511
50	31.4	32.8	45.7	46.5	44.6	48.5	51.4	52.9	50.7	42.6	32.2	25.4	504
* 60	32.4	33.5	44.8	43.9	40.9	44.1	46.7	49.4	49.2	43.0	33.2	26.5	487
70	32.7	33.2	43.0	40.4	36.4	38.8	41.1	45.0	46.3	42.1	33.2	27.0	459
80	32.1	31.8	39.8	36.0	31.5	33.0	35.0	39.1	42.4	40.0	32.6	26.5	419
90	30.8	29.8	36.3	31.1	26.2	27.3	28.5	33.1	37.4	37.4	30.9	25.7	374
Data days	154	139	152	137	175	162	164	186	155	167	163	155	1909

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	66.2	67.2	68.1	66.4	62.3	64.5	65.9	68.1	70.7	69.7	67.5	63.7	66.9
100	43.9	45.0	46.1	43.6	38.9	40.9	42.4	45.1	48.9	47.6	45.0	40.7	44.2
200	14.4	15.9	16.6	14.2	10.3	9.6	10.5	13.5	17.1	16.4	14.8	11.4	13.8

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-11.4	-3.8	2.7	8.8	11.7	18.6	26.1	28.4	23.6	15.7	.3	-11.8	109
Double Pane	2.5	6.2	11.4	13.3	13.4	17.4	21.7	24.2	22.8	18.6	8.7	.8	161
Triple Pane	5.5	7.8	12.1	12.8	12.2	15.0	18.1	20.3	20.0	17.1	9.7	3.7	154
Double + R3	13.5	14.7	19.5	18.3	16.3	18.5	20.9	23.8	25.0	23.1	16.2	10.7	220

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	23.2	29.7	34.9	46.9	56.1	63.2	71.4	69.5	59.1	49.7	36.4	27.8	47.4
Daily Max	36.1	41.1	48.2	62.3	71.4	77.8	88.6	87.0	76.9	65.5	48.5	41.3	62.2
Daily Min	11.5	14.8	21.7	31.9	41.2	48.1	54.1	51.2	42.2	33.6	23.2	17.0	32.6
Extreme Max	72.0	73.0	80.0	90.0	95.0	100.0	108.0	103.0	99.0	90.0	73.0	73.0	88.1
Extreme Min	-35.0	-31.0	-21.0	7.0	14.0	30.0	39.0	32.0	23.0	13.0	-28.0	-23.0	1.9
Degree Days	1296	988	933	543	288	121	11	23	221	474	858	1153	6909

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# BOZEMAN, MONTANA

Lat: 45.7°

Long: 111.0°

Elev: 4754 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	23.6	27.9	43.0	48.8	45.8	52.8	60.5	57.4	46.9	38.2	23.2	17.8	485
40	26.2	29.8	44.3	48.3	44.3	50.3	57.6	55.9	47.3	40.3	25.4	19.8	489
50	27.9	31.1	44.7	46.6	41.6	46.5	53.7	53.4	46.9	41.6	26.8	21.3	481
* 60	28.8	31.7	43.9	43.9	38.2	42.3	48.8	49.9	45.5	42.0	27.6	22.2	464
70	29.0	31.4	42.1	40.4	34.0	37.2	42.9	45.4	42.8	41.2	27.6	22.6	436
80	28.5	30.1	39.0	36.0	29.4	31.7	36.6	39.4	39.2	39.1	27.0	22.2	398
90	27.3	28.2	35.5	31.2	24.4	26.2	29.8	33.4	34.6	36.5	25.7	21.5	354
Data days	159	146	172	180	178	177	186	177	176	177	173	175	2076

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	64.2	64.6	67.2	65.9	59.9	62.3	65.8	68.0	69.2	69.6	63.8	61.0	65.5
100	42.8	42.1	44.5	42.4	36.0	38.2	42.3	45.1	47.1	47.5	41.5	38.7	42.7
200	15.4	15.5	16.8	13.7	9.0	8.3	10.9	13.8	16.5	17.3	13.6	11.6	13.6

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-16.5	-8.0	-1.8	5.1	6.1	13.3	23.0	24.9	18.6	12.1	-7.3	-17.3	52
Double Pane	-1.2	3.6	8.9	11.3	10.0	14.3	20.4	22.4	19.4	16.5	3.2	-3.2	125
Triple Pane	2.6	5.9	10.3	11.4	9.7	12.8	17.4	19.2	17.3	15.6	5.3	.5	127
Double + R3	10.5	12.9	18.1	17.5	14.1	16.7	20.8	23.2	22.3	21.8	11.7	7.3	196

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	20.4	25.9	30.2	42.1	50.9	57.6	66.3	64.9	55.6	46.1	32.2	25.2	43.2
Daily Max	30.7	35.8	41.0	53.7	63.3	70.2	81.5	80.3	69.5	58.7	42.4	34.9	55.3
Daily Min	10.1	15.8	19.2	30.4	38.5	44.9	51.1	49.4	41.5	33.4	21.9	15.5	31.1
Extreme Max	58.0	62.0	70.0	81.0	89.0	91.0	98.0	99.0	95.0	82.0	70.0	59.0	79.6
Extreme Min	-36.0	-29.0	-23.0	2.0	16.0	26.0	32.0	29.0	16.0	9.0	-26.0	-29.0	-9.9
Degree Days	1372	1106	1074	680	429	232	45	70	288	581	976	1229	8082

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# BROWNING, MONTANA

Lat: 48.6°

Long: 113.0°

Elev: 4462 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	19.2	30.4	43.8	53.9	50.8	56.9	60.0	54.7	47.9	38.1	25.1	17.8	498
40	21.3	32.4	45.2	53.4	49.1	54.1	57.1	53.3	48.3	40.2	27.5	19.8	501
50	22.7	33.8	45.6	51.4	46.2	50.1	53.2	50.9	47.9	41.5	29.0	21.4	493
* 60	23.4	34.5	44.7	48.5	42.4	45.5	48.4	47.6	46.5	41.9	29.8	22.3	475
70	23.6	34.1	42.9	44.6	37.7	40.0	42.6	43.3	43.7	41.1	29.8	22.7	446
80	23.2	32.8	39.8	39.8	32.6	34.1	36.3	37.6	40.0	39.0	29.2	22.3	406
90	22.2	30.7	36.2	34.5	27.1	28.2	29.5	31.9	35.3	36.5	27.8	21.6	361
Data days	54	45	131	144	182	137	115	59	125	168	88	83	1331

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	57.5	66.7	67.5	67.8	61.3	62.7	65.1	66.1	69.2	68.6	65.7	59.6	65.4
100	35.6	44.1	45.2	45.6	38.1	39.0	42.1	43.5	47.5	46.1	43.2	36.9	42.8
200	11.3	17.0	16.5	16.3	10.9	9.7	12.2	13.6	17.0	15.3	13.9	8.6	13.8

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-22.7	-7.6	-3.8	5.1	6.0	12.6	19.5	20.0	16.5	10.4	-6.8	-18.6	30
Double Pane	-5.8	4.4	8.0	12.2	10.7	14.5	18.5	19.4	18.5	15.5	4.1	-3.9	116
Triple Pane	-1.2	6.8	9.8	12.4	10.5	13.2	16.0	16.9	16.8	14.9	6.2	.0	122
Double + R3	6.4	14.3	18.0	19.1	15.5	17.6	19.9	21.2	22.2	21.4	12.9	7.0	195

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	18.0	23.6	27.0	38.7	48.2	54.7	62.3	60.5	52.3	44.1	30.7	23.5	40.4
Daily Max	29.0	31.1	38.1	51.0	61.5	68.0	78.0	76.0	65.3	54.6	40.1	32.8	52.3
Daily Min	8.4	10.1	16.2	26.9	35.3	41.2	45.6	43.7	37.0	30.1	19.5	13.4	27.4
Extreme Max	66.0	68.0	72.0	91.0	93.0	98.0	99.0	98.0	94.0	83.0	72.0	69.0	83.7
Extreme Min	-56.0	-46.0	-38.0	-14.0	1.0	21.0	24.0	23.0	.0	-17.0	-39.0	-47.0	-15.5
Degree Days	1457	1159	1178	789	521	315	111	167	395	648	1029	1287	9056

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# BUTTE, MONTANA

Lat: 46.0°

Long: 112.5°

Elev: 5755 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	27.6	29.9	42.0	48.2	43.9	48.2	56.6	56.1	45.2	37.3	27.1	20.8	482
40	29.2	31.5	42.8	47.8	42.0	45.9	53.8	54.6	45.6	39.3	29.3	22.2	483
50	30.1	32.1	42.4	46.0	39.8	42.4	50.2	52.2	45.2	40.1	30.5	23.1	474
* 60	30.4	32.1	41.2	43.4	36.5	38.6	45.6	48.8	43.9	40.1	31.1	23.6	455
70	30.1	31.5	39.1	40.0	32.9	33.9	40.1	44.4	41.2	38.9	30.8	23.4	426
80	28.9	29.9	36.2	35.6	28.9	28.9	34.2	38.5	37.7	37.3	30.2	22.9	389
90	27.3	27.9	32.5	30.8	24.1	23.9	27.8	32.7	33.3	34.5	28.3	21.7	345
Data days	160	168	180	175	165	123	56	48	125	158	158	185	1701

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	65.2	65.1	65.4	65.0	57.2	59.1	64.0	68.2	68.6	68.4	66.6	61.1	64.7
100	43.2	42.6	42.7	41.5	33.8	34.4	39.5	45.3	46.3	46.3	44.3	38.5	41.7
200	14.9	14.7	15.5	13.7	8.7	6.9	8.9	14.4	16.1	16.6	14.9	11.1	13.1

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-20.8	-11.9	-8.0	1.3	2.4	8.5	18.1	20.5	13.6	6.3	-8.5	-22.1	-1
Double Pane	-3.5	1.4	4.8	9.2	8.0	11.1	17.3	19.9	16.4	12.9	3.3	-5.7	94
Triple Pane	1.0	4.4	7.2	10.0	8.3	10.4	15.0	17.4	15.1	12.9	5.7	-1.1	106
Double + R3	9.5	11.9	15.1	16.4	13.2	14.4	18.7	21.8	20.5	19.5	12.8	6.3	179

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	15.1	20.9	25.6	37.7	46.8	53.9	62.2	60.3	50.6	41.1	27.9	19.2	38.5
Daily Max	27.8	32.7	39.1	50.9	60.7	67.9	80.0	78.0	67.5	56.3	40.3	32.5	52.9
Daily Min	1.5	5.5	13.7	25.7	33.5	40.1	45.1	42.5	34.8	26.8	15.0	7.7	24.4
Extreme Max	54.0	60.0	64.0	79.0	88.0	93.0	100.0	99.0	91.0	83.0	68.0	62.0	78.5
Extreme Min	-48.0	-52.0	-36.0	-13.0	12.0	23.0	29.0	26.0	12.0	-19.0	-42.0	-37.0	-11.8
Degree Days	1547	1235	1221	819	564	337	119	166	437	741	1113	1420	9719

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# CHOTEAU, MONTANA

Lat: 47.8°

Long: 112.2°

Elev: 3800 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1978-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	25.0	27.5	42.7	50.6	49.4	55.1	60.3	56.4	47.8	37.9	25.5	19.5	497
40	27.7	29.3	44.0	50.2	47.8	52.5	57.4	54.9	48.3	40.0	28.0	21.7	501
50	29.5	30.6	44.4	48.4	44.9	48.5	53.5	52.4	47.8	41.2	29.5	23.4	494
* 60	30.5	31.2	43.5	45.6	41.2	44.1	48.6	49.0	46.4	41.6	30.4	24.3	476
70	30.8	30.9	41.8	42.0	36.6	38.8	42.8	44.6	43.6	40.8	30.4	24.8	447
80	30.2	29.6	38.8	37.4	31.7	33.1	36.5	38.7	39.9	38.7	29.8	24.3	408
90	28.9	27.8	35.3	32.4	26.3	27.3	29.7	32.8	35.3	36.2	28.3	23.6	363
Data days	122	104	131	149	150	150	141	103	140	151	143	154	1638

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	66.6	65.2	66.9	66.1	60.7	61.4	64.8	66.9	69.2	68.8	67.1	63.6	65.7
100	44.6	42.4	44.8	43.1	37.2	36.7	41.2	44.0	47.1	46.5	45.2	40.6	42.8
200	14.4	14.5	16.3	14.7	10.1	8.3	10.3	13.3	16.1	15.7	14.6	10.8	13.2

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-14.6	-7.7	-1.7	6.2	8.2	15.1	22.9	24.0	18.6	12.5	-3.9	-14.6	64
Double Pane	.3	3.6	8.8	12.2	11.6	15.5	20.3	21.8	19.6	16.6	5.8	-1.2	134
Triple Pane	3.7	5.8	10.3	12.2	11.0	13.8	17.3	18.7	17.5	15.6	7.4	2.1	135
Double + R3	11.8	12.7	18.0	18.3	15.6	17.7	20.7	22.6	22.7	21.8	13.9	9.0	204

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	21.1	26.7	30.5	42.3	51.6	58.7	66.3	64.4	55.0	47.0	33.8	26.4	43.7
Daily Max	33.2	36.6	43.8	55.2	65.4	72.3	82.7	80.8	69.6	59.9	45.4	38.4	57.1
Daily Min	8.2	10.8	18.2	28.0	36.9	44.2	49.2	46.3	38.7	31.1	20.1	14.8	29.0
Extreme Max	66.0	70.0	82.0	85.0	92.0	97.0	105.0	106.0	96.0	87.0	77.0	72.0	86.4
Extreme Min	-44.0	-50.0	-36.0	-16.0	8.0	28.0	33.0	29.0	-5.0	-15.0	-30.0	-38.0	-11.1
Degree Days	1361	1072	1070	681	415	212	47	85	320	558	936	1197	7954

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# COLSTRIP, MONTANA

Lat: 45.9°

Long: 106.6°

Elev: 2540 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	26.0	30.1	44.1	48.2	48.0	56.6	59.6	58.3	53.1	39.4	26.2	19.9	509
40	28.9	32.2	45.5	47.8	46.4	53.8	56.7	56.8	53.6	41.5	28.7	22.1	514
50	30.8	33.5	45.9	46.0	43.6	49.8	52.8	54.3	53.1	42.8	30.3	23.9	506
* 60	31.7	34.2	45.0	43.4	40.0	45.2	48.0	50.7	51.6	43.3	31.2	24.9	489
70	32.1	33.9	43.2	40.0	35.6	39.8	42.3	46.1	48.5	42.4	31.2	25.4	460
80	31.4	32.5	40.1	35.6	30.8	33.9	36.0	40.1	44.4	40.2	30.6	24.9	420
90	30.2	30.5	36.5	30.8	25.6	28.1	29.3	34.0	39.2	37.6	29.0	24.1	374
Data days	87	109	177	165	149	105	91	57	86	105	135	117	1383

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	65.7	67.2	67.9	65.5	60.8	63.6	64.8	68.4	71.4	69.7	65.3	60.4	66.2
100	42.6	45.1	45.5	42.6	37.7	40.1	41.6	45.4	49.0	47.6	42.0	36.9	43.4
200	12.6	16.5	16.6	13.8	9.1	9.1	10.1	13.4	16.7	16.9	12.6	9.5	13.2

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-13.7	-5.4	.7	6.9	9.8	18.8	26.9	29.6	25.0	15.0	-2.9	-15.0	95
Double Pane	1.1	5.6	10.5	12.1	12.3	17.7	22.3	25.0	24.1	18.3	6.5	-1.3	154
Triple Pane	4.4	7.5	11.5	12.0	11.4	15.3	18.6	21.0	21.0	16.9	7.9	2.1	149
Double + R3	12.6	14.7	19.2	17.7	15.6	19.0	21.5	24.5	26.2	23.1	14.5	9.2	217

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	21.0	26.9	32.3	44.7	54.3	62.7	71.5	70.1	59.0	48.6	34.3	25.5	46.0
Daily Max	34.2	39.8	45.8	59.3	69.2	77.6	89.2	88.1	75.9	64.8	47.5	38.2	60.9
Daily Min	7.7	13.9	18.9	30.1	39.4	47.7	53.8	52.1	42.0	32.4	21.1	12.8	31.1
Extreme Max	67.0	70.0	80.0	87.0	96.0	102.0	107.0	111.0	102.0	94.0	79.0	71.0	88.9
Extreme Min	-40.0	-31.0	-28.0	3.0	13.0	28.0	34.0	33.0	18.0	7.0	-32.0	-35.0	-2.3
Degree Days	1356	1053	1001	624	319	105	12	24	203	500	915	1202	7314

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# DILLON, MONTANA

Lat: 45.3°

Long: 112.6°

Elev: 5057 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	26.6	32.8	44.8	53.2	50.4	56.0	63.2	57.7	51.2	41.8	28.5	22.0	528
40	29.5	35.1	46.2	52.7	48.7	53.3	60.1	56.2	51.7	44.1	31.3	24.5	533
50	31.4	36.6	46.6	50.8	45.8	49.3	56.1	53.7	51.2	45.5	33.0	26.4	526
* 60	32.4	37.3	45.7	47.9	42.0	44.8	51.0	50.2	49.7	45.9	34.0	27.5	508
70	32.7	36.9	43.9	44.1	37.4	39.4	44.8	45.7	46.8	45.0	34.0	28.0	478
80	32.1	35.4	40.7	39.3	32.3	33.6	38.2	39.6	42.8	42.7	33.3	27.5	437
90	30.8	33.2	37.0	34.0	26.9	27.8	31.1	33.6	37.8	39.9	31.6	26.7	390
Data days	156	163	180	164	169	172	172	168	164	179	147	175	2009

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	66.7	68.6	68.0	67.4	60.7	62.8	66.5	67.6	70.5	70.4	66.9	63.7	66.8
100	44.7	46.3	45.4	44.5	35.9	38.6	42.9	44.8	48.5	48.5	45.0	41.1	44.0
200	15.7	16.8	16.9	15.6	9.0	9.1	11.6	13.8	17.4	17.5	15.8	12.0	14.3

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-12.2	-2.8	.5	7.4	7.9	14.5	23.1	23.8	20.5	14.9	-1.4	-12.7	83
Double Pane	2.0	7.7	10.5	13.3	11.6	15.3	20.8	21.9	21.3	18.9	8.0	.6	151
Triple Pane	5.2	9.3	11.6	13.1	11.1	13.7	17.8	18.8	18.9	17.6	9.3	3.7	150
Double + R3	13.3	16.7	19.4	19.5	15.8	17.8	21.5	23.0	24.4	24.3	16.2	11.0	222

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	22.2	27.4	31.5	42.1	50.7	57.5	65.1	63.4	54.7	46.1	33.5	25.7	43.4
Daily Max	34.2	38.3	45.2	55.9	65.4	73.8	82.6	81.1	71.4	61.4	46.5	37.2	57.9
Daily Min	11.7	15.3	21.5	29.9	36.9	42.7	47.7	45.1	37.2	30.7	21.5	15.1	29.7
Extreme Max	60.0	65.0	74.0	84.0	91.0	94.0	99.0	100.0	93.0	86.0	79.0	65.0	82.6
Extreme Min	-36.0	-40.0	-26.0	-1.0	15.0	25.0	30.0	25.0	9.0	-13.0	-31.0	-35.0	-6.3
Degree Days	1327	1053	1039	687	443	235	50	100	319	586	945	1218	8002

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# ENNIS, MONTANA

Lat: 45.4°

Long: 111.7°

Elev: 4927 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1978-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	23.8	29.7	43.6	46.3	45.4	51.5	56.3	52.8	46.7	37.2	26.0	19.9	479
40	26.4	31.7	45.0	45.9	43.9	49.1	53.6	51.5	47.1	39.2	28.5	22.1	483
50	28.2	33.1	45.4	44.2	41.2	45.4	49.9	49.2	46.7	40.4	30.0	23.9	477
* 60	29.1	33.7	44.5	41.7	37.8	41.2	45.4	46.0	45.3	40.8	31.0	24.9	461
70	29.3	33.4	42.7	38.4	33.7	36.3	39.9	41.8	42.6	40.0	31.0	25.4	434
80	28.8	32.0	39.6	34.2	29.1	30.9	34.0	36.3	39.0	38.0	30.3	24.9	397
90	27.6	30.0	36.1	29.6	24.2	25.6	27.7	30.8	34.4	35.5	28.8	24.1	354
Data days	92	102	142	105	154	133	121	109	108	122	104	99	1391
* measured data													

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	64.8	66.2	67.7	63.5	57.7	60.2	63.7	65.7	68.7	68.5	66.2	62.1	64.7
100	43.6	44.0	45.0	39.9	32.9	36.2	39.9	42.8	46.6	46.6	44.9	39.9	41.9
200	16.1	16.7	16.8	13.0	7.3	8.4	9.5	13.0	16.3	16.7	15.8	12.7	13.4

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-14.5	-5.3	-.4	3.5	5.5	12.3	20.0	21.2	17.2	11.0	-3.5	-13.9	53
Double Pane	-.0	5.5	9.7	10.1	9.6	13.5	18.2	19.7	18.6	15.6	6.1	-.7	126
Triple Pane	3.4	7.4	11.0	10.4	9.4	12.2	15.7	17.0	16.8	14.9	7.7	2.5	128
Double + R3	11.1	14.5	18.7	16.3	13.9	16.2	19.0	20.9	21.9	21.1	14.2	9.4	197

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	22.6	27.5	31.3	41.8	50.4	57.0	64.7	63.1	54.1	45.8	33.8	26.8	43.3
Daily Max	31.8	36.0	43.4	55.4	65.5	73.3	82.8	81.0	71.0	59.5	44.0	35.6	56.7
Daily Min	11.6	14.7	20.3	28.3	35.8	42.3	47.3	44.9	37.5	30.9	21.9	16.5	29.4
Extreme Max	58.0	62.0	76.0	82.0	94.0	97.0	100.0	97.0	92.0	86.0	71.0	68.0	82.0
Extreme Min	-43.0	-43.0	-29.0	-7.0	15.0	24.0	32.0	27.0	12.0	-10.0	-27.0	-37.0	-7.0
Degree Days	1314	1050	1045	696	453	249	68	94	336	595	936	1184	8020

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# FORT BENTON, MONTANA

Lat: 47.8°

Long: 110.7°

Elev: 2600 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1978-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	21.1	26.2	41.2	46.3	46.4	55.3	62.7	56.9	47.5	35.6	23.4	16.2	478
40	23.4	28.0	42.5	45.8	44.8	52.6	59.6	55.4	48.0	37.5	25.6	18.1	481
50	24.9	29.2	42.9	44.2	42.1	48.7	55.6	52.9	47.5	38.7	27.0	19.5	473
* 60	25.7	29.8	42.1	41.7	38.6	44.2	50.5	49.4	46.1	39.1	27.9	20.3	455
70	26.0	29.5	40.4	38.3	34.4	38.9	44.5	45.0	43.4	38.3	27.9	20.7	427
80	25.4	28.3	37.5	34.2	29.7	33.2	37.9	39.1	39.7	36.3	27.3	20.3	388
90	24.4	26.5	34.1	29.6	24.7	27.4	30.8	33.1	35.1	34.0	25.9	19.7	345
Data days	121	111	154	141	153	132	131	150	135	154	129	154	1665

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	64.3	65.1	67.4	64.8	60.7	63.1	66.3	66.9	69.4	68.9	65.7	60.3	65.6
100	40.9	42.1	45.0	41.9	37.6	38.7	42.7	43.5	47.3	46.4	43.1	36.6	42.5
200	10.6	13.4	16.2	13.3	10.0	8.6	11.0	12.4	16.2	15.3	12.5	7.6	12.5

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-20.2	-9.2	-1.6	6.2	9.6	17.7	26.7	27.2	20.3	11.4	-6.0	-19.6	62
Double Pane	-3.9	2.5	8.5	11.5	11.9	17.0	22.6	23.5	20.4	15.4	4.0	-4.9	128
Triple Pane	.3	4.9	9.9	11.3	11.1	14.8	19.0	19.9	18.0	14.6	5.9	-.9	128
Double + R3	8.1	11.7	17.4	16.9	15.1	18.4	22.2	23.5	23.0	20.4	12.2	5.8	194

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	18.8	26.1	31.8	45.2	55.0	62.0	69.7	68.0	57.3	47.9	33.6	24.3	45.1
Daily Max	32.1	34.9	43.9	59.7	68.4	74.9	85.3	83.3	72.7	62.7	45.0	37.6	58.5
Daily Min	8.7	10.4	19.2	31.5	40.9	48.6	53.4	50.9	42.2	33.2	21.9	15.1	31.5
Extreme Max	72.0	70.0	82.0	93.0	94.0	108.0	111.0	109.0	101.0	92.0	78.0	73.0	90.4
Extreme Min	-58.0	-45.0	-42.0	-6.0	14.0	27.0	31.0	27.0	9.0	-6.0	-36.0	-59.0	-11.8
Degree Days	1451	1089	1029	594	317	141	16	33	253	530	942	1262	7657

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# GLASGOW, MONTANA

Lat: 48.2°

Long: 106.6°

Elev: 2095 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	23.8	29.9	44.8	50.3	53.6	59.3	64.6	55.5	47.0	38.5	24.8	18.4	510
40	26.5	32.0	46.2	49.9	51.8	56.5	61.5	54.1	47.5	40.6	27.2	20.4	514
50	28.2	33.3	46.7	48.1	48.7	52.2	57.3	51.6	47.0	41.9	28.7	22.1	505
* 60	29.1	34.0	45.8	45.4	44.7	47.5	52.1	48.3	45.6	42.3	29.6	23.0	487
70	29.4	33.7	43.9	41.7	39.8	41.8	45.9	43.9	42.9	41.4	29.6	23.4	457
80	28.8	32.3	40.7	37.2	34.4	35.6	39.1	38.1	39.3	39.3	29.0	23.0	416
90	27.6	30.3	37.1	32.2	28.6	29.4	31.8	32.3	34.7	36.8	27.5	22.3	370
Data days	162	169	180	138	153	143	130	144	171	183	173	179	1925

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	63.5	66.0	67.6	65.9	62.7	63.9	66.0	65.5	68.5	68.7	65.3	60.1	65.6
100	40.4	43.0	44.7	43.0	39.1	39.9	42.2	41.7	45.9	46.0	42.3	37.3	42.4
200	11.7	14.4	15.5	13.8	10.2	9.7	10.9	11.8	15.3	14.8	12.4	9.1	12.6

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-24.4	-14.7	-2.0	7.7	13.2	20.6	29.5	27.3	19.9	11.8	-9.1	-24.4	55
Double Pane	-5.3	.6	9.2	13.0	14.9	19.0	24.4	23.4	20.1	16.4	2.8	-6.8	131
Triple Pane	-.1	4.1	10.7	12.7	13.5	16.4	20.3	19.7	17.8	15.5	5.3	-1.8	134
Double + R3	8.8	12.4	18.9	18.6	18.0	20.1	23.4	23.1	22.7	21.9	12.3	6.0	206

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	10.5	14.5	28.4	44.4	55.5	63.6	72.2	68.9	57.2	45.5	28.0	15.8	42.2
Daily Max	19.6	23.7	37.4	55.7	68.4	75.9	86.7	83.5	70.5	57.9	37.9	24.9	53.7
Daily Min	1.4	5.2	19.4	33.0	42.6	51.2	57.6	54.3	43.8	33.1	18.0	6.6	30.7
Extreme Max	61.0	59.0	78.0	93.0	102.0	97.0	108.0	108.0	102.0	96.0	70.0	64.0	86.7
Extreme Min	-50.0	-33.0	-29.0	-4.0	16.0	36.0	39.0	33.0	21.0	7.0	-21.0	-31.0	-1.2
Degree Days	1690	1414	1135	618	330	131	15	34	262	605	1110	1525	8869

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# GLENDIVE, MONTANA

Lat: 47.1°

Long: 104.7°

Elev: 2071 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	24.6	27.4	43.2	48.1	52.2	56.1	58.3	55.0	48.7	35.8	24.4	17.1	490
40	27.3	29.3	44.5	47.7	50.5	53.4	55.5	53.6	49.1	37.8	26.7	19.0	494
50	29.1	30.5	44.9	46.0	47.4	49.3	51.7	51.2	48.7	38.9	28.2	20.5	486
* 60	30.0	31.1	44.1	43.4	43.5	44.8	47.0	47.9	47.2	39.3	29.0	21.3	468
70	30.3	30.8	42.3	39.9	38.7	39.5	41.4	43.6	44.4	38.6	29.0	21.7	440
80	29.7	29.6	39.2	35.6	33.5	33.6	35.3	37.8	40.6	36.6	28.5	21.3	401
90	28.5	27.7	35.7	30.8	27.8	27.8	28.7	32.1	35.9	34.2	27.0	20.7	356
Data days	81	105	124	170	151	155	140	140	138	134	137	108	1583

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	65.5	65.3	67.7	65.7	62.9	63.7	64.6	66.8	70.4	68.0	64.8	58.2	65.7
100	42.8	43.1	45.1	42.7	39.6	39.4	40.3	43.3	48.2	45.7	42.0	35.5	42.6
200	14.0	15.0	15.6	13.6	10.8	9.2	9.4	12.3	16.2	15.0	12.3	8.8	12.8

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-20.0	-12.3	-1.5	8.2	14.5	21.1	28.4	29.7	23.3	12.9	-5.5	-20.7	78
Double Pane	-2.7	1.1	9.1	12.8	15.4	18.9	23.0	24.6	22.2	16.3	4.6	-5.3	139
Triple Pane	1.7	4.2	10.5	12.4	13.7	16.1	18.9	20.5	19.3	15.1	6.4	-1.0	137
Double + R3	10.3	11.6	18.3	17.9	17.9	19.4	21.5	23.6	24.1	20.8	12.9	6.0	204

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	14.9	20.5	30.4	46.4	57.8	65.9	74.0	72.2	60.2	49.4	33.1	21.9	45.7
Daily Max	25.3	28.8	41.4	59.9	71.3	79.6	89.2	87.3	74.9	62.1	43.0	31.0	58.0
Daily Min	3.0	5.3	17.4	32.5	43.0	52.3	58.2	55.0	44.1	33.0	20.2	9.5	31.3
Extreme Max	63.0	73.0	85.0	96.0	104.0	109.0	117.0	113.0	104.0	95.0	76.0	72.0	92.4
Extreme Min	-48.0	-50.0	-34.0	-6.0	16.0	29.0	36.0	32.0	16.0	-13.0	-26.0	-40.0	-7.1
Degree Days	1553	1246	1073	564	246	90	8	13	204	484	957	1336	7774

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# GREAT FALLS, MONTANA

Lat: 47.5°

Long: 111.3°

Elev: 3330 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	24.5	28.1	42.3	48.9	48.9	56.7	62.5	57.0	47.4	36.6	25.7	20.1	498
40	27.2	30.1	43.6	48.4	47.2	54.0	59.5	55.5	47.9	38.6	28.2	22.3	502
50	29.0	31.3	44.0	46.7	44.4	49.9	55.5	53.0	47.4	39.8	29.7	24.1	494
* 60	29.9	32.0	43.1	44.0	40.7	45.3	50.4	49.6	46.0	40.2	30.7	25.1	477
70	30.2	31.7	41.4	40.5	36.2	39.9	44.4	45.1	43.3	39.4	30.7	25.6	448
80	29.6	30.4	38.4	36.1	31.3	34.0	37.8	39.2	39.6	37.4	30.0	25.1	408
90	28.4	28.5	34.9	31.2	26.1	28.1	30.8	33.2	35.0	35.0	28.5	24.3	364
Data days	153	164	185	180	186	180	186	180	180	186	175	165	2120

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	65.1	65.8	67.2	65.0	60.7	62.8	65.5	67.0	69.0	68.4	66.5	62.8	65.6
100	42.7	43.3	45.2	42.0	37.4	38.5	41.9	44.1	46.9	46.2	44.3	39.6	42.7
200	13.2	15.2	16.7	13.5	10.0	8.8	10.6	13.5	16.2	15.8	13.9	10.7	13.2

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-15.5	-7.2	-2.0	6.2	9.3	17.4	26.3	26.7	20.2	12.6	-3.0	-14.0	76
Double Pane	-.4	4.0	8.6	11.9	12.1	16.9	22.4	23.3	20.4	16.3	6.3	-.7	141
Triple Pane	3.2	6.2	10.1	11.8	11.4	14.8	18.8	19.7	18.0	15.3	7.7	2.5	139
Double + R3	11.3	13.2	17.8	17.7	15.7	18.7	22.1	23.5	22.9	21.2	14.2	9.5	207

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	20.5	26.6	30.5	43.4	53.3	60.8	69.3	67.4	57.3	48.3	34.6	26.5	45.0
Daily Max	29.3	35.9	40.4	54.5	65.0	72.1	83.7	81.8	70.0	59.4	43.4	34.7	56.0
Daily Min	11.6	17.2	20.6	32.3	41.5	49.5	54.9	53.0	44.6	37.1	25.7	18.2	33.9
Extreme Max	61.0	64.0	72.0	83.0	90.0	97.0	105.0	106.0	98.0	85.0	72.0	61.0	82.9
Extreme Min	-37.0	-22.0	-19.0	5.0	19.0	32.0	40.0	37.0	23.0	-3.0	-15.0	-43.0	1.5
Degree Days	1380	1075	1070	648	367	162	18	42	260	524	912	1194	7652

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# HAMILTON, MONTANA

Lat: 46.3°

Long: 114.2°

Elev: 3600 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	18.9	25.5	40.3	48.1	46.7	53.5	60.1	61.2	44.4	37.3	22.7	16.0	474
40	19.9	26.9	41.1	47.6	44.7	50.9	57.2	59.6	44.8	39.3	24.5	17.1	473
50	20.5	27.4	40.7	45.9	42.4	47.1	53.3	56.9	44.4	40.1	25.5	17.8	462
* 60	20.8	27.4	39.5	43.3	38.9	42.8	48.5	53.2	43.1	40.1	26.0	18.2	441
70	20.5	26.9	37.5	39.8	35.0	37.7	42.7	48.4	40.5	38.9	25.8	18.0	411
80	19.7	25.5	34.7	35.5	30.7	32.1	36.4	42.0	37.1	37.3	25.3	17.7	374
90	18.7	23.8	31.2	30.7	25.7	26.5	29.6	35.7	32.8	34.5	23.7	16.8	329
Data days	151	127	166	175	168	147	128	91	136	177	173	169	1808

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	58.0	62.5	64.7	65.0	58.5	61.8	65.2	69.0	67.4	68.3	62.8	56.2	64.1
100	36.3	40.1	41.8	41.3	34.3	37.3	41.3	45.6	44.7	46.3	40.1	33.9	41.0
200	11.3	13.6	14.2	12.9	8.8	8.4	10.2	13.5	14.7	16.1	11.8	8.5	12.2

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-20.0	-7.6	-.4	7.6	9.2	15.3	23.8	27.2	17.9	10.7	-6.8	-19.0	57
Double Pane	-5.4	2.6	8.4	12.5	12.0	15.4	20.8	24.2	18.5	15.2	2.9	-5.5	121
Triple Pane	-1.3	4.6	9.5	12.2	11.2	13.6	17.6	20.7	16.5	14.5	4.9	-1.6	122
Double + R3	5.2	10.7	16.2	17.8	15.5	17.4	20.9	24.8	21.2	20.5	10.8	4.4	185

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	24.8	31.2	36.2	45.7	53.5	59.8	67.5	65.5	56.7	46.5	34.8	27.9	45.9
Daily Max	34.4	39.3	48.6	60.0	68.4	75.1	85.2	83.1	72.2	60.0	45.6	36.6	59.2
Daily Min	15.7	19.2	26.2	33.2	39.7	45.7	50.8	48.8	41.7	33.6	25.2	19.1	33.3
Extreme Max	62.0	71.0	74.0	90.0	102.0	100.0	103.0	102.0	98.0	90.0	72.0	66.0	85.9
Extreme Min	-36.0	-39.0	-14.0	1.0	18.0	29.0	33.0	32.0	18.0	-1.0	-24.0	-30.0	-8
Degree Days	1246	946	893	579	362	171	27	66	267	574	906	1150	7187

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# HARLOWTON, MONTANA

Lat: 46.4°

Long: 109.8°

Elev: 4167 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	25.7	31.2	45.0	51.2	47.8	53.0	59.0	55.3	49.8	38.9	27.9	22.4	507
40	28.5	33.3	46.4	50.8	46.2	50.4	56.2	53.8	50.3	41.1	30.5	24.9	512
50	30.4	34.8	46.9	48.9	43.5	46.6	52.3	51.4	49.8	42.4	32.2	26.8	505
* 60	31.3	35.5	46.0	46.1	39.9	42.4	47.6	48.1	48.3	42.8	33.2	27.9	489
70	31.6	35.1	44.1	42.4	35.5	37.3	41.9	43.7	45.4	41.9	33.2	28.5	460
80	31.0	33.7	40.9	37.8	30.7	31.8	35.7	38.0	41.6	39.8	32.5	27.9	421
90	29.8	31.6	37.2	32.8	25.5	26.3	29.0	32.2	36.7	37.2	30.9	27.1	376
Data days	79	150	111	117	169	95	93	117	145	127	125	132	1460

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	65.3	66.9	68.2	66.5	60.0	61.9	65.1	66.4	70.0	68.8	66.7	63.9	65.9
100	43.4	44.2	46.0	43.8	36.0	38.3	41.6	43.4	48.1	46.6	44.1	40.7	43.2
200	14.3	15.5	16.8	15.1	9.3	9.2	11.1	13.4	17.1	16.0	14.2	11.3	13.7

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-13.4	-5.5	-.4	6.4	7.3	13.3	22.2	22.8	19.4	12.6	-2.5	-11.5	70
Double Pane	1.1	5.8	10.1	12.4	10.9	14.3	19.7	21.0	20.4	17.0	7.2	1.4	141
Triple Pane	4.4	7.8	11.4	12.4	10.5	12.8	16.8	18.0	18.2	16.0	8.6	4.3	141
Double + R3	12.5	15.2	19.3	18.6	15.0	16.8	20.2	22.0	23.6	22.3	15.5	11.5	212

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	21.7	25.5	30.2	42.1	51.3	57.6	66.0	63.6	54.5	46.1	32.8	26.7	43.3
Daily Max	33.6	38.0	43.4	56.5	66.4	72.2	83.3	81.8	71.4	61.5	45.6	38.3	57.8
Daily Min	9.8	12.9	17.0	27.7	36.2	43.0	48.6	45.3	37.5	30.7	20.0	15.0	28.7
Extreme Max	63.0	74.0	76.0	87.0	93.0	95.0	102.0	101.0	97.0	91.0	78.0	69.0	85.6
Extreme Min	-38.0	-39.0	-30.0	-8.0	4.0	24.0	33.0	29.0	10.0	5.0	-29.0	-39.0	-6.3
Degree Days	1342	1083	1088	710	424	207	46	82	319	561	961	1186	8009

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# HAVRE, MONTANA

Lat: 48.6°

Long: 109.7°

Elev: 2486 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	23.9	28.1	44.0	47.4	51.1	53.6	56.4	51.1	46.2	36.1	25.2	17.5	480
40	26.6	30.0	45.4	47.0	49.4	51.0	53.6	49.8	46.7	38.1	27.6	19.4	484
50	28.3	31.3	45.8	45.3	46.4	47.2	50.0	47.6	46.2	39.3	29.1	21.0	477
* 60	29.2	31.9	44.9	42.7	42.6	42.9	45.5	44.5	44.9	39.7	30.0	21.8	460
70	29.5	31.6	43.1	39.3	37.9	37.7	40.0	40.5	42.2	38.9	30.0	22.3	432
80	28.9	30.3	40.0	35.0	32.8	32.2	34.1	35.1	38.6	36.9	29.4	21.8	395
90	27.7	28.4	36.4	30.3	27.3	26.6	27.7	29.8	34.1	34.5	27.9	21.2	351
Data days	141	140	182	161	157	137	140	104	170	170	174	170	1846

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	64.0	65.4	68.0	65.4	63.3	63.1	64.5	64.6	68.9	67.8	66.0	59.7	65.3
100	40.8	42.3	45.6	42.5	40.2	39.7	40.3	41.0	46.6	44.9	43.6	36.4	42.2
200	11.3	13.7	16.3	13.3	10.9	9.0	9.3	11.2	15.9	14.6	13.5	8.4	12.4

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-19.6	-13.0	-1.0	6.7	12.3	17.8	25.4	24.4	19.3	11.0	-6.5	-21.6	55
Double Pane	-2.7	1.0	9.5	11.9	14.0	16.7	21.1	21.1	19.6	15.3	4.2	-5.6	126
Triple Pane	1.6	4.2	10.9	11.8	12.8	14.5	17.6	17.9	17.4	14.6	6.3	-1.1	128
Double + R3	10.0	11.9	18.8	17.4	17.0	18.0	20.3	21.1	22.2	20.5	13.0	6.1	196

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	16.2	18.9	30.3	45.1	55.7	62.9	71.3	68.0	57.0	46.8	30.9	20.4	43.8
Daily Max	26.3	29.6	41.0	57.6	68.8	75.2	85.9	82.9	71.0	59.8	41.5	30.4	56.0
Daily Min	6.1	8.1	19.5	32.5	42.6	50.6	56.6	53.1	42.9	33.7	20.2	10.3	31.5
Extreme Max	65.0	71.0	77.0	95.0	98.0	107.0	107.0	106.0	98.0	91.0	74.0	71.0	88.4
Extreme Min	-57.0	-48.0	-32.0	-8.0	14.0	29.0	37.0	27.0	18.0	-7.0	-28.0	-36.0	-7.4
Degree Days	1513	1291	1076	597	313	125	20	38	270	564	1023	1383	8213

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# HELENA, MONTANA

Lat: 46.6°

Long: 112.0°

Elev: 4124 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	21.8	26.9	38.8	46.8	44.8	52.0	57.6	54.7	48.7	38.6	25.7	18.3	474
40	24.2	28.7	40.0	46.4	43.3	49.5	54.8	53.3	49.2	40.7	28.2	20.4	478
50	25.8	30.0	40.4	44.7	40.7	45.8	51.1	50.9	48.7	42.0	29.7	22.0	471
* 60	26.6	30.6	39.6	42.2	37.3	41.6	46.5	47.6	47.3	42.4	30.6	22.9	455
70	26.9	30.3	38.0	38.8	33.2	36.6	40.9	43.3	44.5	41.6	30.6	23.4	428
80	26.3	29.0	35.3	34.6	28.7	31.2	34.8	37.6	40.7	39.4	30.0	22.9	390
90	25.3	27.2	32.1	29.9	23.9	25.8	28.3	31.9	36.0	36.9	28.5	22.2	347
Data days	172	154	155	160	157	138	111	132	127	152	129	144	1731

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	62.7	63.5	64.3	64.4	57.9	61.2	65.2	66.4	69.0	68.5	66.6	60.8	64.5
100	40.6	39.9	41.2	40.4	33.5	36.5	41.6	43.0	46.4	45.7	44.5	38.1	41.2
200	13.2	12.8	14.2	11.4	7.5	8.2	10.4	12.7	16.2	15.1	15.0	11.3	12.3

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-19.7	-10.8	-3.6	5.0	7.2	14.4	23.6	24.7	20.0	11.9	-5.4	-17.6	49
Double Pane	-3.4	1.8	7.0	10.9	10.4	14.8	20.3	21.8	20.5	16.5	5.0	-3.2	122
Triple Pane	.8	4.6	8.6	11.0	9.9	13.1	17.1	18.6	18.2	15.6	6.9	.6	125
Double + R3	8.7	11.7	15.9	16.8	14.1	16.8	20.2	22.3	23.3	22.0	13.6	7.6	193

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	18.6	23.2	31.4	43.3	52.9	59.5	68.4	66.2	56.0	45.6	31.6	24.2	43.5
Daily Max	28.8	33.7	42.5	56.1	65.8	72.3	84.4	82.2	70.8	58.8	42.4	34.2	56.1
Daily Min	8.4	12.7	20.2	30.5	39.9	46.6	52.3	50.1	41.2	32.3	20.8	14.2	30.9
Extreme Max	50.0	60.0	70.0	76.0	86.0	88.0	95.0	95.0	91.0	85.0	67.0	59.0	76.9
Extreme Min	-7.0	-11.0	-16.0	12.0	27.0	36.0	42.0	40.0	19.0	21.0	-3.0	-38.0	10.3
Degree Days	1438	1170	1042	651	381	195	31	59	294	601	1002	1265	8129

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# JORDAN, MONTANA

Lat: 47.3°

Long: 106.9°

Elev: 2800 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1978-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	27.6	31.2	46.1	51.2	48.5	54.4	59.6	62.0	50.7	40.1	26.4	18.7	516
40	30.7	33.3	47.5	50.7	46.9	51.8	56.7	60.4	51.2	42.3	28.9	20.8	521
50	32.7	34.7	48.0	48.9	44.0	47.8	52.8	57.7	50.7	43.7	30.5	22.4	513
* 60	33.7	35.4	47.1	46.1	40.4	43.5	48.0	53.9	49.2	44.1	31.4	23.3	496
70	34.0	35.1	45.2	42.4	36.0	38.3	42.3	49.1	46.3	43.2	31.4	23.8	467
80	33.4	33.7	41.9	37.8	31.1	32.6	36.0	42.6	42.3	41.0	30.8	23.3	426
90	32.0	31.5	38.1	32.7	25.9	27.0	29.3	36.1	37.4	38.4	29.2	22.6	380
Data days	118	112	119	120	139	118	118	119	144	150	146	129	1532

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	67.7	68.3	69.2	66.7	61.6	62.3	65.4	69.8	70.8	70.2	67.9	60.1	67.0
100	45.2	46.3	47.3	43.7	38.6	39.6	42.5	46.9	48.8	48.2	45.8	37.2	44.5
200	14.5	17.4	18.1	14.3	9.9	9.0	10.3	14.2	16.9	16.7	14.7	9.1	13.9

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-17.2	-8.4	-.1	8.3	10.7	18.6	27.4	31.4	22.9	14.5	-4.6	-19.7	83
Double Pane	-.2	4.3	10.5	13.4	12.8	17.3	22.6	26.6	22.5	18.3	5.6	-4.2	149
Triple Pane	3.8	6.7	11.7	13.0	11.8	14.9	18.8	22.3	19.7	17.0	7.4	-.0	147
Double + R3	12.8	14.5	19.9	19.0	15.9	18.3	21.6	26.1	24.8	23.4	14.2	7.3	217

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	14.9	21.6	29.6	44.5	55.1	63.5	72.1	70.1	58.2	47.3	31.9	21.2	44.3
Daily Max	28.1	31.7	43.2	59.0	70.0	78.6	90.3	87.7	75.9	62.6	44.8	34.4	59.0
Daily Min	2.7	4.8	16.8	29.6	40.0	48.8	55.3	52.1	41.1	30.3	17.9	8.7	29.1
Extreme Max	62.0	72.0	81.0	94.0	102.0	111.0	112.0	110.0	107.0	93.0	76.0	71.0	91.0
Extreme Min	-51.0	-58.0	-35.0	-13.0	10.0	29.0	31.0	32.0	18.0	-14.0	-31.0	-39.0	-9.8
Degree Days	1553	1215	1097	615	316	127	14	22	240	549	993	1358	8099

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# KALISPELL, MONTANA

Lat: 48.2°

Long: 114.3°

Elev: 2959 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	17.7	21.2	38.4	46.0	47.4	54.2	58.3	55.0	44.8	35.0	15.6	12.0	445
40	18.6	22.3	39.2	45.6	45.4	51.6	55.5	53.6	45.2	36.8	16.9	12.8	443
50	19.2	22.8	38.8	43.9	43.1	47.7	51.7	51.2	44.8	37.6	17.6	13.4	431
* 60	19.4	22.8	37.7	41.4	39.5	43.4	47.0	47.8	43.5	37.6	18.0	13.6	411
70	19.2	22.3	35.8	38.1	35.6	38.2	41.4	43.5	40.9	36.5	17.8	13.5	382
80	18.4	21.2	33.2	34.0	31.2	32.5	35.2	37.8	37.4	35.0	17.4	13.2	346
90	17.5	19.8	29.8	29.4	26.1	26.9	28.7	32.0	33.1	32.3	16.4	12.6	304
Data days	139	150	184	175	167	157	172	173	177	180	168	176	2018

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	56.9	57.0	63.8	63.7	59.5	61.9	63.9	66.4	67.9	67.0	56.2	51.2	62.8
100	37.0	35.9	41.4	40.5	35.9	37.9	40.2	43.3	45.7	44.3	34.9	31.3	40.1
200	12.5	12.3	14.7	12.8	9.7	9.3	10.3	13.0	15.7	14.3	9.7	8.4	12.2

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-24.7	-15.5	-3.6	4.9	8.6	14.5	21.9	23.0	16.4	7.2	-15.1	-25.1	12
Double Pane	-8.2	-2.7	6.3	10.7	11.8	15.1	19.5	21.0	17.8	12.7	-3.5	-9.8	90
Triple Pane	-3.4	.6	7.9	10.8	11.1	13.4	16.6	18.1	16.0	12.5	-.3	-5.1	98
Double + R3	3.5	6.8	14.7	16.5	15.6	17.4	20.0	22.0	21.0	18.5	5.1	.8	161

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	20.3	25.0	33.7	43.7	52.4	58.4	66.0	64.0	54.5	44.4	32.0	24.7	43.4
Daily Max	28.0	34.1	43.2	55.2	65.0	71.4	82.1	80.5	68.9	55.8	39.1	31.2	54.7
Daily Min	12.6	15.8	24.1	32.2	39.8	45.4	49.9	47.4	40.0	32.9	24.9	18.2	32.0
Extreme Max	47.0	53.0	61.0	73.0	87.0	93.0	104.0	105.0	90.0	79.0	64.0	48.0	75.5
Extreme Min	-23.0	-22.0	-29.0	21.0	28.0	31.0	36.0	37.0	23.0	18.0	-28.0	-14.0	6.7
Degree Days	1386	1120	970	639	391	215	47	83	326	639	990	1249	8055

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# LEWISTOWN, MONTANA

Lat: 47.1°

Long: 109.4°

Elev: 3960 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	28.9	31.2	44.6	50.4	49.5	57.1	61.6	56.5	48.6	39.4	26.5	20.9	515
40	32.1	33.3	46.0	49.9	47.8	54.3	58.6	55.0	49.1	41.6	29.0	23.3	519
50	34.2	34.8	46.5	48.1	44.9	50.2	54.6	52.6	48.6	42.9	30.5	25.1	512
* 60	35.2	35.5	45.5	45.4	41.2	45.6	49.7	49.1	47.2	43.3	31.5	26.1	495
70	35.6	35.1	43.7	41.7	36.7	40.2	43.7	44.7	44.3	42.4	31.5	26.7	466
80	34.9	33.7	40.5	37.2	31.7	34.2	37.3	38.8	40.6	40.3	30.9	26.1	426
90	33.5	31.6	36.9	32.2	26.4	28.3	30.3	32.9	35.8	37.7	29.3	25.4	380
Data days	110	157	183	173	176	174	159	133	171	181	157	162	1936

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	68.4	67.4	67.8	66.2	61.2	63.7	65.5	67.1	69.7	69.6	66.5	63.1	66.5
100	46.7	45.6	45.4	43.0	37.6	39.8	42.2	43.8	47.8	47.6	44.3	40.4	43.7
200	15.7	17.0	17.3	13.9	10.3	10.1	11.5	13.2	17.2	16.9	14.4	11.5	14.1

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-12.1	-7.7	-2.0	4.9	7.3	14.7	23.3	24.1	19.0	13.0	-4.3	-13.9	66
Double Pane	2.8	4.6	9.1	11.5	11.2	15.6	20.7	21.8	20.0	17.3	5.8	-.3	140
Triple Pane	6.0	7.0	10.7	11.7	10.7	14.0	17.6	18.7	17.8	16.2	7.5	2.9	140
Double + R3	14.7	14.7	18.8	17.9	15.5	18.2	21.2	22.7	23.1	22.6	14.3	10.1	213

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	19.6	22.5	28.6	40.8	50.5	57.3	66.1	64.4	54.9	46.1	32.2	25.6	42.5
Daily Max	31.0	34.4	39.8	53.5	63.8	70.4	81.9	80.4	69.6	59.8	43.8	37.0	55.6
Daily Min	8.2	10.5	17.4	28.0	37.2	44.2	50.2	48.3	40.1	32.3	20.5	14.2	29.4
Extreme Max	66.0	64.0	74.0	89.0	92.0	99.0	100.0	103.0	96.0	89.0	77.0	74.0	85.4
Extreme Min	-34.0	-42.0	-28.0	-17.0	11.0	28.0	33.0	32.0	20.0	-10.0	-29.0	-32.0	-5.4
Degree Days	1397	1143	1149	760	456	225	66	84	322	581	984	1219	8386

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# LIBBY, MONTANA

Lat: 48.4°

Long: 115.6°

Elev: 2053 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	14.6	17.8	36.2	44.8	45.5	52.1	58.4	54.8	41.3	29.5	12.8	9.5	417
40	15.4	18.7	36.9	44.4	43.6	49.6	55.6	53.4	41.7	31.1	13.8	10.2	414
50	15.9	19.1	36.5	42.8	41.3	45.9	51.8	51.0	41.3	31.7	14.4	10.6	402
* 60	16.0	19.1	35.4	40.4	37.9	41.7	47.1	47.7	40.1	31.7	14.7	10.8	382
70	15.9	18.7	33.7	37.2	34.1	36.7	41.5	43.4	37.7	30.8	14.6	10.7	354
80	15.2	17.8	31.2	33.1	30.0	31.3	35.3	37.7	34.5	29.5	14.3	10.5	320
90	14.4	16.6	28.0	28.7	25.0	25.9	28.7	32.0	30.5	27.3	13.4	10.0	280
Data days	109	141	179	156	177	170	161	169	166	170	148	128	1874

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	56.6	54.9	63.0	63.2	57.8	60.4	63.4	66.0	66.0	64.4	52.2	48.0	61.6
100	35.3	34.7	40.6	39.6	34.0	36.1	39.7	42.9	43.5	42.4	31.8	27.7	38.8
200	9.5	11.2	13.6	12.1	8.5	8.5	10.4	12.9	14.3	13.2	7.9	5.9	11.2

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-25.8	-15.9	-2.9	6.0	9.4	15.2	23.2	24.0	16.3	4.6	-17.1	-25.5	11
Double Pane	-9.7	-3.8	6.2	11.1	11.9	15.2	20.2	21.5	17.0	10.0	-5.4	-10.8	83
Triple Pane	-4.7	-.5	7.6	11.0	11.1	13.4	17.1	18.4	15.2	10.1	-1.9	-6.0	90
Double + R3	1.6	5.0	14.0	16.3	15.2	17.0	20.3	22.2	19.6	15.3	3.1	-.7	148

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	22.0	28.0	36.4	45.8	54.4	60.4	67.5	65.3	57.0	46.3	32.5	26.8	45.3
Daily Max	30.8	38.9	49.5	62.2	72.1	78.2	89.7	87.5	76.1	59.4	40.2	33.3	59.9
Daily Min	13.1	17.1	23.2	29.4	36.7	42.5	45.2	43.0	37.9	33.2	24.7	20.3	30.6
Extreme Max	56.0	63.0	75.0	89.0	102.0	102.0	108.0	109.0	102.0	89.0	67.0	57.0	85.0
Extreme Min	-38.0	-37.0	-20.0	-5.0	12.0	24.0	30.0	28.0	16.0	-7.0	-26.0	-24.0	-3.7
Degree Days	1290	991	919	596	341	159	48	64	252	613	985	1179	7437

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# LIVINGSTON, MONTANA

Lat: 45.7°

Long: 110.6°

Elev: 4490 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1978-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	19.5	25.6	44.4	48.2	48.8	57.8	60.0	57.4	44.8	34.5	27.0	16.6	484
40	21.6	27.3	45.7	47.8	47.2	55.0	57.1	55.9	45.2	36.4	29.5	18.4	487
50	23.1	28.5	46.2	46.0	44.4	50.9	53.2	53.4	44.8	37.6	31.1	19.9	478
* 60	23.8	29.0	45.3	43.4	40.7	46.2	48.4	49.9	43.5	38.0	32.1	20.7	461
70	24.0	28.8	43.5	39.9	36.2	40.7	42.6	45.4	40.9	37.2	32.1	21.1	432
80	23.5	27.6	40.3	35.6	31.3	34.7	36.3	39.4	37.4	35.3	31.5	20.7	393
90	22.6	25.8	36.7	30.8	26.1	28.7	29.5	33.4	33.1	33.0	29.9	20.1	349
Data days	79	64	108	90	71	37	122	85	73	99	64	86	978

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	60.7	62.9	68.7	65.0	62.0	65.1	65.7	67.5	68.7	68.2	66.9	58.7	65.6
100	39.8	41.6	47.3	42.1	38.8	41.1	42.4	44.2	46.6	46.1	45.0	36.1	43.0
200	13.7	15.0	18.9	14.2	10.6	10.6	11.0	12.6	15.9	16.0	14.7	9.2	13.6

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-16.9	-8.0	1.8	6.0	8.6	16.5	24.4	26.1	18.7	11.2	-1.3	-14.5	72
Double Pane	-2.7	2.9	11.1	11.7	11.7	16.7	21.0	23.0	19.0	15.1	7.5	-2.1	134
Triple Pane	1.0	5.1	12.0	11.6	11.1	14.7	17.8	19.6	16.9	14.2	8.7	1.0	133
Double + R3	7.9	11.7	19.6	17.5	15.6	18.8	21.0	23.4	21.6	19.8	15.3	7.2	199

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	24.7	28.5	33.4	43.6	52.4	59.2	68.2	66.4	57.4	48.6	35.4	30.1	45.8
Daily Max	34.3	38.8	44.5	56.4	66.0	73.0	85.0	83.4	72.5	61.6	45.2	39.2	58.4
Daily Min	15.1	18.2	22.2	30.7	38.7	45.4	51.3	49.4	42.2	35.5	25.5	21.2	33.0
Extreme Max	59.0	67.0	72.0	87.0	93.0	105.0	102.0	101.0	98.0	85.0	73.0	68.0	84.2
Extreme Min	-34.0	-45.0	-21.0	-10.0	12.0	28.0	35.0	32.0	20.0	-8.0	-27.0	-26.0	-3.4
Degree Days	1204	968	974	650	380	165	36	55	242	488	872	1052	7086

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# MILES CITY, MONTANA

Lat: 46.4°

Long: 105.8°

Elev: 2364 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	27.6	31.1	44.5	50.2	48.6	56.5	59.7	55.4	48.3	38.9	24.8	19.8	505
40	30.7	33.2	45.9	49.7	47.0	53.8	56.8	54.0	48.8	41.1	27.2	22.1	510
50	32.7	34.6	46.3	47.9	44.1	49.8	52.9	51.6	48.3	42.4	28.7	23.8	503
* 60	33.7	35.3	45.4	45.2	40.5	45.2	48.1	48.2	46.9	42.8	29.5	24.8	485
70	34.0	35.0	43.6	41.6	36.0	39.8	42.3	43.9	44.1	41.9	29.5	25.3	457
80	33.4	33.6	40.4	37.1	31.2	33.9	36.1	38.1	40.3	39.8	28.9	24.8	417
90	32.0	31.4	36.8	32.1	25.9	28.0	29.4	32.3	35.6	37.2	27.5	24.1	372
Data days	160	165	185	177	183	166	143	122	168	161	176	182	1988

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	67.2	67.8	68.0	66.7	61.0	63.2	64.6	66.4	69.6	69.3	65.5	62.4	66.1
100	44.4	45.5	45.7	43.9	37.2	38.5	40.3	42.6	47.2	46.8	43.1	39.4	43.0
200	14.6	16.3	17.0	14.7	9.1	8.3	9.4	11.7	16.3	16.1	13.6	10.8	13.2

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-15.8	-9.4	-.2	8.7	12.6	21.1	30.0	30.2	23.7	15.0	-5.5	-16.9	93
Double Pane	.5	3.7	10.1	13.4	13.8	18.9	24.0	24.9	22.4	18.2	4.7	-2.3	152
Triple Pane	4.2	6.3	11.3	13.0	12.5	16.2	19.7	20.7	19.4	16.8	6.5	1.4	148
Double + R3	13.1	14.2	19.2	18.7	16.4	19.5	22.2	23.8	24.0	22.9	13.1	8.7	215

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	16.5	20.3	30.9	45.7	57.4	65.6	75.3	72.6	61.0	49.0	32.6	23.2	46.0
Daily Max	27.4	31.8	42.3	58.6	70.6	78.5	90.2	87.5	75.2	62.4	43.5	33.6	58.6
Daily Min	5.6	8.7	19.4	32.8	44.1	52.6	60.4	57.7	46.7	35.5	21.7	12.8	33.3
Extreme Max	62.0	66.0	83.0	91.0	99.0	104.0	109.0	110.0	105.0	93.0	75.0	69.0	89.0
Extreme Min	-37.0	-37.0	-27.0	7.0	15.0	32.0	41.0	35.0	20.0	9.0	-23.0	-31.0	.5
Degree Days	1504	1252	1057	579	276	99	6	6	174	502	972	1296	7723

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# MISSOULA, MONTANA

Lat: 46.9°

Long: 114.0°

Elev: 3223 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	18.1	21.7	37.2	43.1	43.8	52.7	56.5	54.4	43.0	35.3	18.7	13.2	437
40	19.1	22.9	37.9	42.7	42.0	50.1	53.8	53.0	43.4	37.2	20.2	14.1	436
50	19.7	23.3	37.6	41.2	39.8	46.3	50.2	50.6	43.0	38.0	21.1	14.7	425
* 60	19.9	23.3	36.5	38.8	36.5	42.1	45.6	47.3	41.7	38.0	21.5	14.9	406
70	19.7	22.9	34.7	35.7	32.9	37.1	40.1	43.1	39.2	36.8	21.3	14.8	378
80	18.9	21.7	32.1	31.9	28.9	31.6	34.2	37.4	35.9	35.3	20.9	14.5	343
90	17.9	20.3	28.8	27.6	24.1	26.1	27.8	31.7	31.7	32.7	19.6	13.8	302
Data days	157	157	177	174	163	149	154	139	159	179	170	157	1935

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	58.0	59.3	63.6	62.5	57.8	63.0	64.5	66.8	67.3	67.9	60.4	52.8	63.1
100	36.3	37.8	41.2	39.1	34.0	39.0	40.5	43.9	45.1	46.0	37.3	31.6	40.2
200	9.5	12.1	14.4	11.7	8.4	9.2	9.9	13.0	15.4	16.1	9.2	7.3	11.8

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-25.0	-14.6	-3.6	4.2	8.0	15.2	23.1	24.4	16.4	7.9	-12.5	-25.0	18
Double Pane	-8.3	-2.1	6.1	9.8	10.9	15.3	19.9	21.7	17.4	13.2	-1.2	-9.4	93
Triple Pane	-3.4	1.1	7.6	10.0	10.3	13.5	16.8	18.5	15.6	12.9	1.6	-4.7	99
Double + R3	3.6	7.3	14.2	15.4	14.4	17.1	19.8	22.1	20.3	18.9	7.4	1.4	161

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	19.4	25.7	34.7	44.7	53.6	60.2	68.4	66.1	55.8	44.9	31.9	23.6	44.2
Daily Max	28.6	35.7	45.6	57.9	67.8	74.8	86.3	83.8	71.4	58.0	40.9	31.6	57.0
Daily Min	10.1	15.6	23.7	31.4	39.4	45.5	50.4	48.3	40.1	31.7	22.9	15.5	31.3
Extreme Max	48.0	56.0	70.0	78.0	86.0	96.0	105.0	105.0	86.0	79.0	58.0	46.0	76.2
Extreme Min	-14.0	18.0	-8.0	20.0	22.0	31.0	36.0	32.0	24.0	17.0	2.0	-15.0	13.7
Degree Days	1414	1100	939	609	365	176	22	57	292	623	993	1283	7873

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# PLENTYWOOD, MONTANA

Lat: 48.8°

Long: 104.6°

Elev: 2024 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1978-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	25.0	31.0	45.0	46.4	50.2	56.4	61.0	57.6	47.1	36.5	23.3	18.3	497
40	27.7	33.2	46.4	46.0	48.6	53.7	58.0	56.1	47.6	38.5	25.5	20.3	501
50	29.5	34.6	46.8	44.3	45.6	49.7	54.1	53.6	47.1	39.7	26.9	21.9	493
* 60	30.4	35.3	45.9	41.8	41.9	45.1	49.2	50.1	45.8	40.1	27.7	22.9	476
70	30.7	34.9	44.1	38.5	37.3	39.7	43.3	45.6	43.0	39.3	27.7	23.3	447
80	30.1	33.5	40.8	34.3	32.2	33.9	36.9	39.6	39.4	37.3	27.2	22.9	408
90	28.9	31.4	37.2	29.7	26.8	28.0	30.0	33.6	34.8	34.9	25.8	22.2	363
Data days	111	121	146	136	108	117	112	121	136	148	144	136	1536

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	65.7	67.4	68.3	64.8	61.5	62.8	64.8	67.1	68.4	68.2	64.2	59.8	65.5
100	43.2	44.9	46.3	41.9	37.4	39.0	40.9	44.0	45.5	45.8	41.4	36.9	42.5
200	13.1	16.4	17.8	13.6	8.9	9.2	10.2	13.1	14.6	14.8	11.4	8.7	12.8

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-25.4	-14.4	-5.3	3.9	10.6	18.6	25.8	27.6	19.6	10.5	-10.5	-25.1	35
Double Pane	-5.5	1.0	7.4	10.2	13.0	17.6	21.9	23.9	20.0	15.2	1.6	-7.1	119
Triple Pane	-.1	4.6	9.6	10.5	12.0	15.2	18.4	20.2	17.7	14.5	4.2	-2.1	124
Double + R3	9.3	13.1	18.2	16.4	16.4	18.9	21.6	23.9	22.7	20.6	11.0	5.8	197

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	7.9	13.6	24.2	42.1	54.1	62.5	69.5	68.1	56.7	45.8	28.0	15.1	40.8
Daily Max	18.9	23.6	35.4	55.4	68.2	75.7	83.9	83.2	71.2	57.6	38.1	26.3	53.3
Daily Min	-4.7	-.6	12.3	28.5	39.7	48.9	53.3	50.8	40.9	29.7	15.2	4.3	26.7
Extreme Max	54.0	68.0	77.0	92.0	103.0	104.0	117.0	107.0	101.0	89.0	74.0	68.0	87.9
Extreme Min	-51.0	-58.0	-38.0	-6.0	11.0	22.0	30.0	30.0	9.0	-7.0	-31.0	-42.0	-10.6
Degree Days	1770	1439	1265	687	344	135	21	37	275	595	1110	1547	9225

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# POLSON, MONTANA

Lat: 47.7°

Long: 114.2°

Elev: 2949 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	13.9	20.7	38.7	46.8	47.5	52.6	59.0	55.3	44.4	34.0	15.9	12.1	440
40	14.6	21.9	39.4	46.4	45.5	50.1	56.1	53.9	44.9	35.8	17.2	12.9	438
50	15.1	22.3	39.0	44.7	43.1	46.3	52.3	51.5	44.4	36.5	17.9	13.5	426
* 60	15.2	22.3	37.9	42.1	39.6	42.1	47.6	48.1	43.2	36.5	18.3	13.8	406
70	15.1	21.9	36.0	38.8	35.6	37.0	41.9	43.8	40.6	35.4	18.1	13.6	377
80	14.5	20.7	33.4	34.6	31.3	31.6	35.7	38.0	37.1	34.0	17.8	13.3	341
90	13.7	19.4	30.0	29.9	26.1	26.1	29.0	32.2	32.8	31.4	16.7	12.7	299
Data days	149	161	186	180	181	143	147	172	177	185	164	167	2012

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	48.6	57.2	64.9	64.8	59.8	61.5	64.5	66.9	68.3	67.4	58.0	52.5	63.1
100	28.6	35.5	42.6	41.7	36.1	37.7	40.7	43.9	45.9	45.3	36.6	31.7	40.3
200	8.5	12.1	15.7	13.2	9.5	8.7	10.4	13.3	15.6	15.4	10.8	9.0	12.2

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-24.0	-13.7	-2.3	6.2	9.1	14.9	23.3	24.6	18.0	8.0	-12.8	-20.9	30
Double Pane	-8.9	-1.9	7.0	11.5	12.1	15.1	20.3	21.9	18.6	12.9	-2.2	-7.6	98
Triple Pane	-4.3	1.1	8.4	11.4	11.3	13.4	17.2	18.7	16.5	12.5	.6	-3.5	103
Double + R3	1.7	7.0	15.1	17.0	15.7	17.0	20.5	22.5	21.3	18.2	5.7	1.8	163

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	24.9	27.9	35.1	44.8	53.0	59.8	67.4	65.7	56.8	46.3	34.5	29.7	45.6
Daily Max	31.0	35.3	44.0	55.7	65.1	72.1	82.3	80.3	69.3	55.9	41.5	35.4	55.8
Daily Min	18.7	20.4	26.2	33.9	40.8	47.4	52.4	51.1	44.2	36.6	27.5	24.0	35.4
Extreme Max	58.0	65.0	72.0	77.0	89.0	93.0	104.0	101.0	91.0	82.0	65.0	62.0	80.0
Extreme Min	-30.0	-27.0	-10.0	-1.0	17.0	30.0	37.0	33.0	25.0	1.0	-21.0	-14.0	3.5
Degree Days	1201	996	954	623	389	180	57	57	264	609	934	1096	7360

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# RED LODGE, MONTANA

Lat: 45.2°

Long: 109.3°

Elev: 5548 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1978-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	28.7	32.2	43.9	47.9	45.0	50.4	54.0	51.3	48.5	40.8	29.6	23.3	495
40	31.9	34.4	45.2	47.5	43.5	47.9	51.4	49.9	49.0	43.1	32.4	26.0	502
50	34.0	35.8	45.7	45.8	40.9	44.3	47.9	47.7	48.5	44.4	34.1	28.0	497
* 60	35.0	36.6	44.8	43.2	37.5	40.3	43.6	44.6	47.1	44.9	35.2	29.2	481
70	35.4	36.2	43.0	39.7	33.4	35.5	38.3	40.6	44.3	44.0	35.2	29.8	455
80	34.7	34.7	39.8	35.4	28.9	30.2	32.7	35.2	40.5	41.7	34.5	29.2	417
90	33.3	32.5	36.3	30.7	24.0	25.0	26.6	29.9	35.8	39.0	32.7	28.3	374
Data days	124	123	153	143	153	147	155	136	147	153	150	155	1739

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	68.0	68.0	67.8	64.9	57.6	59.3	62.0	64.2	69.2	70.2	68.4	65.1	65.4
100	46.5	45.8	45.8	41.8	33.3	35.0	38.3	41.4	47.2	48.5	46.8	42.4	42.8
200	16.9	17.2	17.2	13.5	7.8	7.8	9.3	12.4	17.1	18.1	16.8	13.1	14.0

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-10.0	-4.7	-2.5	2.7	4.0	10.8	18.8	20.4	17.7	13.3	-1.3	-10.8	58
Double Pane	3.9	6.5	8.7	9.9	8.7	12.6	17.3	19.0	19.3	17.8	8.3	2.1	134
Triple Pane	6.7	8.4	10.3	10.4	8.8	11.5	14.9	16.5	17.3	16.8	9.6	4.9	136
Double + R3	15.1	15.9	18.4	16.6	13.5	15.5	18.2	20.3	22.8	23.4	16.8	12.3	208

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	22.4	25.5	28.6	39.6	48.8	55.7	64.3	63.0	53.3	45.1	32.4	26.4	42.2
Daily Max	33.2	36.5	40.0	51.2	60.8	67.9	78.6	77.3	66.2	57.1	42.9	36.4	54.1
Daily Min	11.5	14.5	17.1	27.9	36.8	43.4	49.9	48.7	40.3	33.1	21.9	16.3	30.2
Extreme Max	70.0	63.0	70.0	78.0	85.0	92.0	98.0	95.0	90.0	83.0	73.0	63.0	80.1
Extreme Min	-36.0	-25.0	-30.0	-10.0	7.0	25.0	30.0	28.0	9.0	7.0	-25.0	-31.0	-4.1
Degree Days	1291	1070	1098	773	473	256	70	98	333	593	962	1174	8191

Montana Department of Natural Resources and Conservation  
Compiled by: Fowlkes Engineering, Bozeman, MT

# SIDNEY, MONTANA

Lat: 47.7°

Long: 104.2°

Elev: 1928 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1978-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	21.3	27.2	43.9	42.0	44.7	52.8	54.9	50.9	47.4	37.0	25.6	17.5	465
40	23.6	29.1	45.3	41.6	43.2	50.3	52.2	49.6	47.9	39.1	28.0	19.5	469
50	25.2	30.3	45.7	40.1	40.6	46.5	48.7	47.4	47.4	40.3	29.5	21.0	462
* 60	26.0	30.9	44.8	37.8	37.3	42.2	44.3	44.3	46.0	40.7	30.5	21.9	446
70	26.2	30.6	43.0	34.8	33.2	37.2	39.0	40.3	43.3	39.9	30.5	22.3	420
80	25.7	29.4	39.9	31.0	28.7	31.7	33.2	35.0	39.6	37.8	29.8	21.9	383
90	24.7	27.5	36.3	26.8	23.8	26.2	27.0	29.7	35.0	35.4	28.3	21.2	342
Data days	83	120	131	101	63	55	62	53	73	87	119	104	1051

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	62.3	65.7	68.6	62.2	58.5	60.3	61.9	64.4	69.7	68.3	66.0	59.5	64.3
100	39.7	43.2	46.3	39.6	36.1	36.0	38.0	41.2	47.6	45.4	42.9	35.7	41.3
200	11.4	15.2	17.3	12.6	9.3	7.7	8.8	11.7	16.2	14.9	12.6	7.3	12.3

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-25.5	-14.2	-3.0	3.0	9.1	17.9	24.4	25.3	20.5	12.0	-6.4	-22.5	40
Double Pane	-6.7	.1	8.4	9.0	11.4	16.7	20.4	21.6	20.5	16.1	4.4	-6.0	116
Triple Pane	-1.4	3.4	10.1	9.4	10.6	14.4	17.0	18.2	18.1	15.2	6.4	-1.4	119
Double + R3	7.0	11.1	18.3	14.7	14.5	17.8	19.7	21.3	23.0	21.2	13.3	5.9	187

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	12.1	18.2	27.9	44.0	55.2	63.5	70.8	69.2	57.7	47.2	30.5	19.2	43.1
Daily Max													
Daily Min													
Extreme Max	DATA NOT AVAILABLE												
Extreme Min													
Degree Days	1640	1310	1150	630	315	118	17	33	253	552	1035	1420	8473

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# THOMPSON FALLS, MONTANA

Lat: 47.6°

Long: 115.3°

Elev: 2463 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1978-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	18.3	18.3	37.2	43.0	42.3	49.3	56.9	53.6	44.2	36.6	14.5	9.1	423
40	19.3	19.3	37.9	42.6	40.5	46.9	54.1	52.2	44.6	38.6	15.7	9.8	421
50	19.9	19.7	37.6	41.1	38.4	43.4	50.5	49.9	44.2	39.4	16.3	10.2	410
* 60	20.1	19.7	36.5	38.8	35.2	39.4	45.9	46.6	42.9	39.4	16.7	10.4	391
70	19.9	19.3	34.6	35.7	31.7	34.7	40.4	42.4	40.3	38.2	16.5	10.3	364
80	19.1	18.3	32.1	31.8	27.8	29.6	34.4	36.8	36.9	36.6	16.2	10.1	329
90	18.1	17.2	28.8	27.5	23.3	24.4	28.0	31.2	32.6	33.9	15.2	9.5	289
Data days	79	92	114	126	120	77	91	69	52	70	60	49	999

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	59.4	54.0	63.4	61.9	54.5	59.7	64.6	66.6	67.4	68.5	55.5	46.1	62.1
100	37.3	32.1	41.7	38.2	30.5	36.4	40.9	43.9	44.5	46.5	34.3	26.8	39.4
200	10.3	9.6	15.1	11.0	6.8	9.7	10.3	13.3	14.4	15.2	8.8	6.9	11.5

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-19.1	-11.8	-.9	5.9	8.4	14.7	23.4	25.0	19.8	11.5	-12.6	-23.2	41
Double Pane	-5.1	-1.5	7.5	10.7	10.9	14.5	20.1	21.8	19.5	15.5	-2.5	-9.6	101
Triple Pane	-1.2	1.1	8.6	10.6	10.2	12.8	16.9	18.5	17.1	14.6	.2	-5.3	103
Double + R3	5.1	6.3	14.8	15.7	14.1	16.1	20.0	22.0	21.5	20.3	5.0	-.3	160

Table 4: CLIMATOLOGICAL DATA (°F)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	26.5	33.0	38.0	46.9	55.0	61.2	68.5	67.2	59.2	48.1	36.3	30.1	47.6
Daily Max	34.1	42.3	49.9	61.3	70.7	76.6	87.8	86.3	76.2	61.2	44.3	36.4	60.7
Daily Min	18.8	23.6	26.0	32.5	39.3	45.7	49.2	48.1	42.1	35.0	28.3	23.7	34.4
Extreme Max	56.0	64.0	78.0	90.0	97.0	100.0	109.0	107.0	106.0	89.0	65.0	58.0	85.0
Extreme Min	-36.0	-30.0	-10.0	17.0	20.0	30.0	35.0	32.0	24.0	18.0	-13.0	-25.0	5.4
Degree Days	1164	891	847	556	311	134	32	46	197	519	864	1083	6644

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# WEST YELLOWSTONE, MONTANA

Lat: 44.9°

Long: 111.1°

Elev: 6665 ft

Table 1: MONTHLY AVERAGE SOLAR RADIATION ON TILTED SURFACES FACING SOUTH 1977-1982  
(thousands of Btu's per square foot per month)

Tilt (deg)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
30	25.4	28.5	44.0	50.9	46.2	52.5	57.3	47.7	52.3	43.9	21.0	18.5	488
40	28.2	30.5	45.4	50.5	44.7	50.0	54.5	46.5	52.8	46.3	23.0	20.5	492
50	30.1	31.8	45.8	48.6	42.0	46.2	50.8	44.4	52.3	47.8	24.2	22.1	486
* 60	31.0	32.4	44.9	45.9	38.5	42.0	46.2	41.5	50.7	48.3	25.0	23.1	469
70	31.3	32.1	43.1	42.2	34.3	37.0	40.6	37.8	47.7	47.3	25.0	23.5	441
80	30.7	30.8	40.0	37.6	29.7	31.5	34.6	32.8	43.6	44.9	24.5	23.1	403
90	29.5	28.9	36.4	32.6	24.6	26.0	28.2	27.8	38.6	42.0	23.2	22.4	360
Data days	115	136	151	141	141	153	154	110	123	120	106	129	1579

\* measured data

Table 2: AVERAGE UTILIZABILITY (60° tilt)  
(percent of total energy having flux greater than threshold level)

Level Btu/sqft-hr	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0	100	100	100	100	100	100	100	100	100	100	100	100	100
50	66.8	65.2	67.1	66.2	58.4	61.5	64.5	65.8	71.4	71.5	62.2	61.1	65.6
100	46.4	43.7	44.5	42.6	33.7	37.0	40.7	43.1	49.5	49.9	40.8	40.0	43.0
200	18.7	17.3	17.1	13.3	7.8	8.0	10.2	13.3	18.1	18.8	13.9	13.6	14.2

Table 3: AVERAGE NET SOLAR GAINS OF SOUTH-FACING WINDOWS  
(thousands of Btu's per square foot per month)

Window type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Single Pane	-20.9	-14.1	-7.4	-.3	.7	8.3	16.2	14.0	15.9	9.7	-16.8	-25.7	-21
Double Pane	-2.9	.5	6.1	8.8	7.2	11.6	16.4	15.1	19.0	16.7	-2.5	-7.4	88
Triple Pane	1.7	3.9	8.6	9.9	7.8	11.0	14.5	13.6	17.5	16.4	1.2	-2.2	103
Double + R3	10.6	11.8	17.3	16.9	13.0	15.5	18.4	17.7	23.8	24.2	8.3	5.8	183

Table 4: CLIMATOLOGICAL DATA (°F)

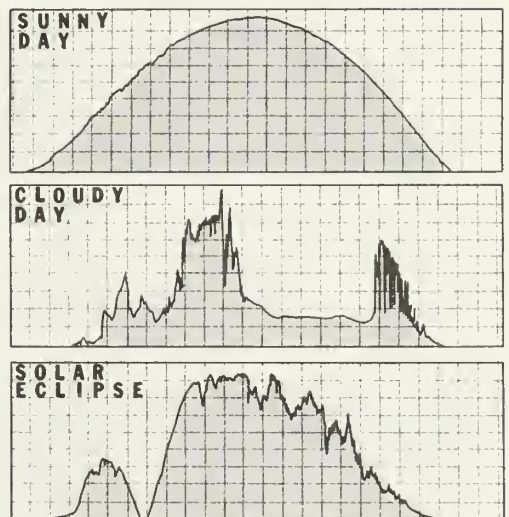
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Daily Avg	12.9	16.8	22.4	33.9	44.1	51.5	59.6	57.3	48.1	37.8	22.7	14.1	35.2
Daily Max	24.2	31.2	38.1	48.0	59.3	67.7	79.9	77.3	66.3	53.3	34.9	26.1	50.6
Daily Min	1.5	2.3	6.6	19.8	28.8	35.2	39.3	37.2	29.8	22.2	10.5	2.1	19.7
Extreme Max	46.0	56.0	61.0	72.0	83.0	91.0	95.0	96.0	91.0	79.0	64.0	54.0	74.1
Extreme Min	-60.0	-52.0	-43.0	-17.0	.0	19.0	20.0	18.0	11.0	-4.0	-36.0	-52.0	-16.2
Degree Days	1638	1361	1340	947	636	392	151	230	491	836	1265	1592	10879

Montana Department of Natural Resources and Conservation  
Compiled by Fowlkes Engineering, Bozeman, MT

# GUIDELINES FOR SOLAR HEATING DESIGN AND PERFORMANCE ESTIMATION

*"We are all working together to one end, some with knowledge and design, and others without knowing what they do."*

*Marcus Aurelius*





## 4.1 Some Basic Solar Heating System Design Considerations

The cardinal rule in solar heating system design is KEEP IT SIMPLE. Rube Goldberg design fantasies bristling with multiple heat exchangers, pumps, fans, controls, coils, valves, dampers, and vents, should be avoided unless you have competent and extensive engineering design assistance. You should stick to standard, proven designs.

A solar heating system is EXPENSIVE, normally taking ten to twenty years to pay for itself. It should therefore be designed and constructed to last longer than twenty years and to have minimal maintenance in order to be economically viable.

Solar radiation is a VERY DIFFUSE form of energy. A surface the size of this page will receive about 100 kWh (341,000 Btus) each year in Montana. A solar heating system may convert about one-third of this—or 33 kWh (11,700 Btus)—into usable energy. A typical household will need about 1,000 times this amount of energy each year for heating, lighting, and appliances.

Active solar heating systems move the solar energy through several heat exchangers before it is delivered to the end load. Inefficiency along the “links of this chain” will accumulate. For example, if there are three “links” that are each only 80 percent efficient, the efficiency of the system will be  $80\% \times 80\% \times 80\%$ , or 51%! ALL DETAILS of the system must be designed, sized, and built right to maintain acceptable performance.

Operation of pumps, fans, dampers, etc. in active solar systems is usually controlled by electronic or pneumatic CONTROLS connected to various SENSORS. Errors in sensor mounting, control adjustments, and wiring can have dramatic effects on system efficiency. For example, if the controls malfunctioned and turned on the collector pumps at night, there could be large losses of heat, or the system might even freeze and rupture.

The collector should face south and NOT BE SHADED by trees or buildings. Even shade from a tree with no leaves will seriously reduce the heat output of a collector. The sun angles given in Section 4.6 will help determine shading.

Passive solar heating systems will need special glazing or movable insulation (to control heat loss) if they are to achieve efficient performance in midwinter. If large areas of glass are used, the heat storage system must be carefully designed and adequately sized to prevent overheating. The temperature of a sunspace can easily reach an uncomfortable 95 degrees F on a sunny winter day if there is insufficient storage mass.

The nemesis of active air solar systems is LEAKAGE. Special dampers should be used and all ductwork, collectors, and plenums should be carefully sealed. A completed system should be tested for leaks.

Liquid collectors must be protected from FREEZING and the freeze protection must be 100 percent FAIL SAFE. The long-term effects of corrosion should be carefully evaluated.

Most of the serious failures of solar heating systems currently in the field relate to at least one of the design or operational flaws listed above.

## 4.2 Active Solar Heating System Performance Estimation

This section presents a simplified method to estimate how much solar heat an active solar system will deliver. You will use table 1 of the Solar Data Tables, Section 3, for your site. More accurate and detailed

design methods are available; see Section 4.7. This simplified method should be used as a guide; it is much better than "guessing and hoping" and its use will ensure that your performance expectations are reasonable.

We begin by classifying the collectors to be used as ABOVE, AVERAGE, and BELOW. These classifications relate to the thermal efficiency and (usually) the cost of the units. For example, a well-insulated, double-glazed, selective surface, liquid collector using low-iron glazing would be classified as ABOVE. A single-glazed, back-pass, air collector would be AVERAGE. A homemade, front-pass air collector with modest insulation and perhaps a few air leaks would be BELOW. If in doubt, you should assume your collector is AVERAGE.

The table below shows the expected average conversion efficiency for the three classes of systems. Conversion efficiency is the amount of energy DELIVERED by the active solar system divided by the solar energy RECEIVED on the surface of the collectors.

System Classification	Conversion Efficiency
Above	0.30 to 0.40
Average	0.20 to 0.30
Below	0.00 to 0.20

To estimate the heat output of your solar system, take the monthly solar radiation from table 1 for the particular site at the tilt corresponding to the collector's mounting. This solar radiation is multiplied by the total collector (glazing) area and the conversion efficiency to estimate the monthly solar heat output.

---

**Example 1:** Estimate the solar heat delivered during January by a solar heating system in Great Falls. The system uses 300 square feet of liquid collectors having a selective surface and two low-iron glazings. The collectors face south and are tilted at 50 degrees.

**Solution:**

- 1) Select a conversion efficiency of 0.35
- 2) Read solar radiation from table 1 for Great Falls, for January, for a tilt of 50 degrees:  
20,000 Btus/sq ft/month
- 3) Solar heat =  $20,000 \times 300 \times 0.35 = 3,045,000$  Btus

---

**Example 2:** Estimate the annual solar heat delivered by a high-quality solar domestic hot-water system in Great Falls. The collector panels face south, are mounted at a 45 degree tilt, and have a total area of 60 square feet.

**Solution:**

- 1) Select a conversion efficiency of 0.35
  - 2) Read annual solar radiation from table 1 for Great Falls for tilts of 40 degrees (502,000 Btus) and 50 degrees (494,000 Btus). Interpolate to get the solar radiation at 45 degrees: 498,000 Bts/sq ft/year
  - 3) Solar heat =  $498,000 \times 60 \times 0.35 = 10,458,000$  Btus/year  
(Note: This is about 50 percent of the total heat required to heat water for a typical family.)
-

**Example 3:** A homemade solar collector is constructed having dimensions 8 feet by 4 feet by 8 inches deep. The sides and back of the box are insulated with one inch of fiberglass and the inside of the box is painted black. The box is glazed with a 4 feet by 8 feet sheet of plastic, and all joints are caulked with silicone.

The box is mounted on the south-facing wall of the house in Great Falls. The collector box is connected through the walls, to the living room, with two ducts. A thermostat switch mounted in the collector closes when the temperature in the collector is above 80 degrees F. This switch turns on a 100 cubic feet per minute (cfm) fan, which circulates house air through the collector. A damper closes the ducts when the fan is off.

How much solar heat will this system produce each year? If this solar heat replaces electricity costing \$0.06 per kWh, how much money will be saved each year? (3,414 Btus = 1 kWh)

**Solution:**

- 1) Select a conversion efficiency of 0.20
  - 2) From table 1 for Great Falls, at a 90 degree tilt, find the annual solar radiation: 364,000 Btus/sq ft
  - 3) Solar heat =  $364,000 \times 32 \times 0.20 = 2,329,600$  Btus
  - 4) Annual savings =  $\$0.061 \times 2,329,600/3,414 = \$41.62$
- 

This simplified performance estimation procedure assumes the collector efficiency is the same during winter and summer. Keep in mind that real collectors lose more heat in the winter and less in the summer, so your monthly calculations will be somewhat distorted by this fact. The solar energy collected during the summer may not be useful, which would lead to an over-production of energy savings.

### 4.3 Passive Solar Performance Estimation

On a clear day, if the sun shines through a window into an insulated room, the temperature in the room will normally rise. The room itself is acting as a low-temperature solar collector, but since there are no fans or pumps required to “move” the solar heat into the room, this is termed “passive” solar heating. Due to the low operating temperature of the passive “collector,” its efficiency is quite high, ranging from 0.45 to 0.65 during the day.

The same glass that collects heat efficiently during the day will lose large amounts of heat during the night in cold weather. During a sunny, winter day in Montana a south-facing window will gain heat for about five hours and lose heat for the other nineteen hours! During a cloudy day the window will lose heat for twenty-four hours a day. The designer must weigh the solar gains against the added heat losses to arrive at a sensible passive solar design that will give a NET GAIN of energy.

Designers may attempt to exploit this passive solar heating effect by putting extra south-facing windows into buildings or by adding greenhouses or sunspaces to the buildings. The crux of the passive solar design issue is to:

- a) select a passive solar collector glazing system that will provide a net gain of heat, and
- b) provide adequate heat storage so that the maximum inside temperatures during clear days are not uncomfortable.

Table 3 is intended to help the designer evaluate different passive solar window systems. In the Solar Data Tables for each of the thirty Montana sites, table 3 can be used to estimate the thermal performance of vertical passive solar windows. For more detailed performance calculations see Section 4.7.

We have considered four "typical" window systems; single-, double-, and triple-glazing, and double-glazing with movable, nighttime insulation. For each of these systems we have calculated the daytime solar gains and subtracted the twenty-four-hour, daily heat losses to produce an AVERAGE NET SOLAR GAIN for each month. These results are tabulated in table 3. The details of this calculation, and the assumptions used, are described in Section 2.3. If you are not familiar with this background material, read Section 2.3.

There are some noteworthy thermal features of south-facing glazing in table 3 that are common to all sites in Montana:

- a) Single-glazing is a net loser of energy during most of the winter at all sites.
- b) Double-glazing is a net energy loser at most locations during December (the month which typically has the minimum solar radiation) and during January, the coldest month.
- c) The annual net energy gains of double- and triple-glazing are similar; reduced losses balance reduced solar gains.
- d) Only the system with the movable insulation shows significant net heat gains during the entire winter season.
- e) All glazing systems show the highest monthly net solar gains occur during the summer, which may add unwanted cooling loads.
- f) There is a marked drop in net solar gains between October and November for all uninsulated systems.

These data emphasize the sensitivity of net passive solar heating gains to the heat loss characteristic of windows. The potential for improving the net solar gain has stimulated development of low-loss glazings and movable insulation systems. Improved systems should eventually be widely available at a reasonable cost.

Table 3 illustrates the dramatic improvement in solar heat gain with the addition of R-3, movable, night insulation. It should be noted that there are several practical and operational problems associated with building a movable insulation system that will achieve an R-3 level of insulation. Our research has shown that it is very difficult to get an adequate seal around the edges of a movable insulation panel or curtain. Unwanted air leaks and circulation will drastically reduce the effective insulation value of the system. We have some data on very thick panels and curtains (R-12 to R-20) which show effective insulation values of only R-2 to R-5. It is very difficult to build a movable insulation system having an effective insulating value of more than R-3 to R-5.

During a cold night, when moist air from the living space leaks into the cavity between the window and the insulating curtain, it will condense and sometimes freeze. This water may deteriorate the window sill or the insulation. The movable insulation may not move if it is frozen along its edges. The designer should consider the effects of condensation.

If an (inside) movable insulation system is in place during a sunny day, the space between the insulation and the glazing will reach high temperatures. These high temperatures may damage the insulation and the glazing sealants, and may even cause the glazing to break. The designer should account for these situations.

---

**Example 1:** A residence in Great Falls has a total of 70 square feet of double-glazed, south-facing windows. What is the net solar energy gain of these windows during March? What is the value of the solar heat if it replaces electricity costing \$0.6/kWh? (3,414 Btus = 1 kWh)

**Solution:**

- 1) From table 3 for Great Falls, under March, for double pane, read the Net Solar Gain: 8,600 Btus/sq ft/month
  - 2) Total Solar Gain = 70 sq ft  $\times$  8,600 Btus/sq ft = 602,000 Btus
  - 3) Savings =  $\$0.06 \times 602,000 \text{ Btus} / 3,414 \text{ Btus} = \$10.58$
- 

**Example 2:** A company will install R-3 movable insulation on my double-glazed, south-facing windows in Great Falls. The insulation costs \$7.00 per square foot and I plan to use it from November through April each year. If electricity costs \$0.06/kWh, how long will it take for the insulation to pay for itself? (3,414 Btus = 1 kWh)

**Solution:**

- 1) Add up the net solar gains for double pane in Great Falls from November through April: 46,000 Btus/sq ft
  - 2) Add up the net solar gains for double pane + R-3 in Great Falls from November through April: 104,900 Btus/sq ft
  - 3) Heat saved = 104,900 - 46,000 = 58,900 Btus/sq ft
  - 4) Value =  $\$0.06 \times 58,900 / 3,414 = \$1.03/\text{sq ft}/\text{year}$
  - 5) Answer: Pays for itself in less than seven years
- 

An attached greenhouse that is always open to (integral with) the living space will perform like a window without movable insulation. Table 3 can be used directly to estimate the net solar gain of an integral sunspace having vertical glazing. If the sunspace has overhead glazing, the designer will have to compute the net energy gain using solar radiation data from table 1, at the appropriate tilt, and the procedure described in Section 2.3. In the interest of energy conservation, it is clear from table 3 that the greenhouse or sunspace should be insulated or shut off from the living space in midwinter.

If the sunspace is separated from the living space by an insulated wall, the system will be operated much like an active, solar collector: when the sun is out and the air in the sunspace is warm, this solar heated air is circulated from the sunspace into the living space using a fan or by opening (connecting) doors or windows. When the sunspace begins to get cold, the fan is shut off, or the doors are closed. Note that this shutting off and opening up procedure also resembles the operation of movable insulation.

If the isolated sunspace or greenhouse is operated like an active solar collector, you can use the procedure in Section 4.2 to estimate its performance. The efficiency of the sunspace collector will probably be only AVERAGE or BELOW due to heat loss, air leaks, and thermal capacity. If the glazing is at different tilts (as in the typical greenhouse) you can work out the solar heat gain from each tilt, and its respective area, and add the results to get the total solar heat gain.

Opening and closing the doors or windows to the greenhouse or sunspace is often done manually (if someone is at home and thinks of doing it). Some building monitoring data have shown relatively poor performance for sunspaces that could be attributed to poor control of the shutting off and opening up.

The simple notion of adding a greenhouse and thus getting a place for plants and "free heat" for the house obscures a fairly complicated design problem. Plants have one set of requirements for temperature, humidity, and light, while people have somewhat different requirements. Connecting the greenhouse and the people house in a mutually satisfying way while keeping within a modest energy budget requires careful design.

Table 1 may be helpful for estimating the ventilation requirements of a greenhouse during the summer. Table 1 shows that the average solar gains of the overhead glass are about twice the solar gains of vertical glass during the summer months. The overhead glass transmits light needed by the growing plants. The solar heat gains of overhead glazing are large during the summer when they are not needed (and must be vented), and relatively small during the winter when they are needed.

## **4.4 Economic Considerations**

Some of the example problems given in the design section of this manual considered elementary economics. Economic considerations center around the replacement of purchased energy with solar energy. The solar energy itself is "free," but we must buy and maintain extra equipment in order to capture solar energy. An economic analysis usually compares the cost of this equipment with the accumulated savings.

All economic analyses depend on predictions of future inflation rates, fossil fuel costs, tax laws, equipment life, etc. These quantities must normally be projected some ten or twenty years into the future to solve the economics problem. Small changes in the assumed values of these quantities can make dramatic changes in the economic conclusions. Because of the uncertainty in this type of calculation and the variety of individual economic circumstances, we cannot make a general recommendation on how you might do your economic analysis.

## **4.5 Correction Factors for East or West Orientations**

All the solar radiation data in this manual are based on measurements with the solar collector facing true south. If your collector is facing within 30 degrees of true south you can generally use the data from table 1 and the error will be no more than 10 percent. If you orient collectors facing farther to the east or west their performance will be noticeably poorer, especially during the winter months.

To help the designer estimate solar gains on east- or west-facing windows, we present the graph and table of correction factors shown below. These factors are based on work by T. Kusuda and K. Ishi at the National Bureau of Standards. These factors were derived for Great Falls but should be adequate for all Montana sites.

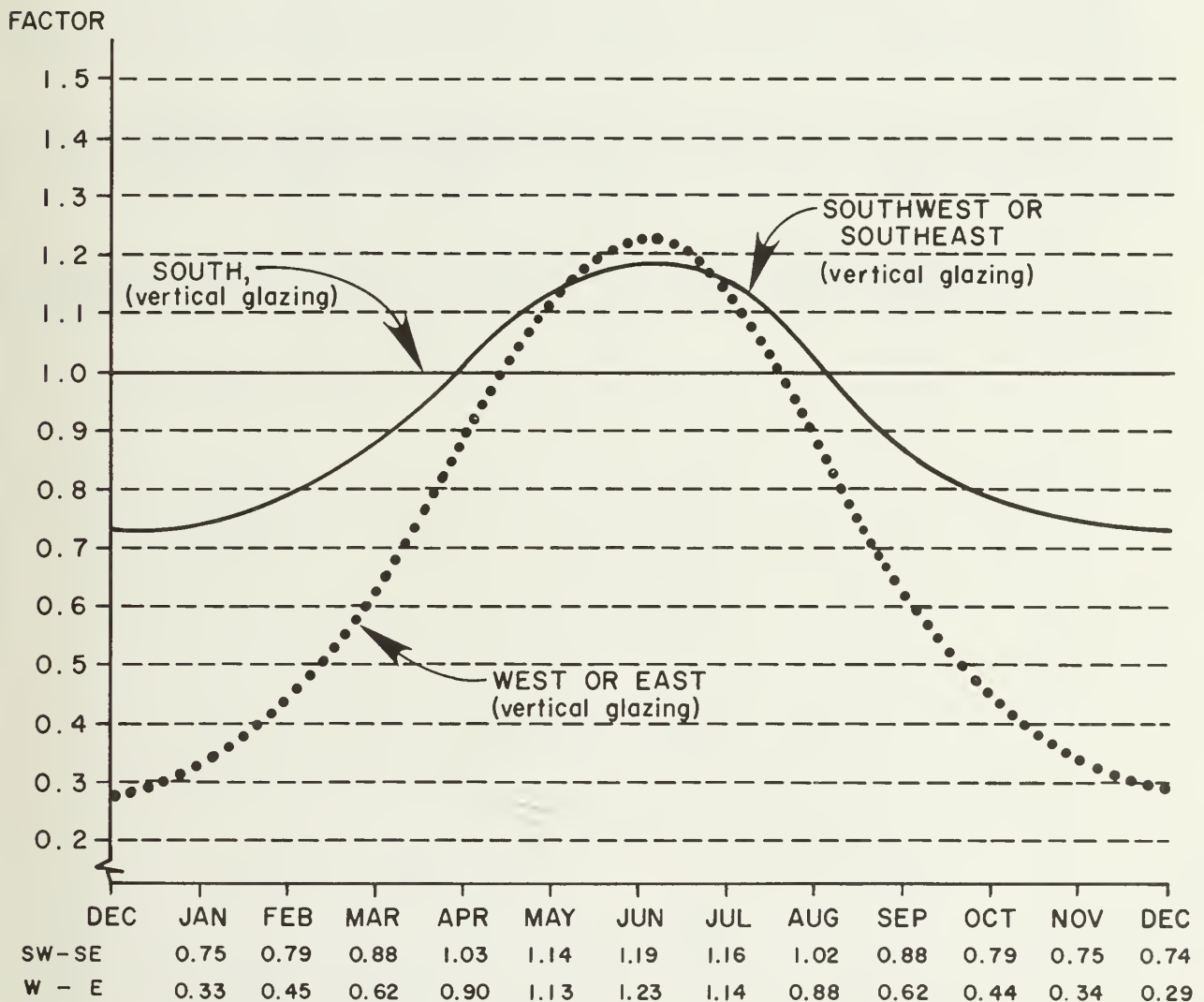
Note that the factors are given for both southwest (or southeast) orientations and for west (or east) orientations. The factors change throughout the year. To use the curves select the orientation and the month of the year. Read the factor from the vertical axis at this point. Multiply this factor by the vertical solar radiation for that month from table 1 in the Solar Data Tables.

The shape of the curves clearly demonstrates that east- or west-facing collectors are not appropriate for solar heating. During the winter, when we need heat, the east (or west) glazings receive greatly reduced solar radiation. During the summer, the east (or west) glazings receive more solar radiation than the south glazing, which adds to any overheating problems.

**Example:** Estimate the solar radiation during February on an east-facing wall in Great Falls.

**Solution:**

- 1) From table 1 for Great Falls, under February, at a tilt of 90 degrees, read the solar radiation: 28,500 Btus/sq ft
- 2) From the graph or table, for February, for an east (or west) orientation curve, read the factor: 0.45
- 3) The answer is  $0.45 \times 28,500 = 12,825$  Btus/sq ft



Factors to convert monthly average radiation on vertical, south-facing surfaces to solar radiation on vertical surface facing east or west of south.

## 4.6 Solar Position and Clear Day Solar Radiation

The table below is reproduced from the Handbook of Fundamentals prepared by the American Society of Heating, Refrigeration and Air Conditioning Engineers. The table is valid for 48 degrees north latitude and sea level. All values are shown for the twenty-first day for each month during the year. The time-of-day is in solar time, which will usually be within thirty minutes of Mountain Standard Time for Montana.

The table shows the position of the sun in terms of **altitude**, the angle in degrees between the sun and the horizon, and **azimuth**, the angle between true south and the bearing of the sun. Note that at solar noon, the azimuth of the sun is 0 degrees or true south. The solar positions in these tables may be helpful in determining the shading of a solar collector due to trees, buildings, or overhanging roof projections.

The table also shows the hourly solar radiation, or insolation, on clear days, on surfaces that are a) normal to (directly facing) the sun, b) horizontal, and c) south-facing and tilted up from horizontal. The daily total radiation on these surfaces is also shown in the table.

The table was calculated for sea level conditions. The solar radiation in Montana is slightly larger because there is less moisture in the atmosphere and because there is less atmosphere between Montana and the sun due to our elevation above sea level. To correct the table for Montana you should multiply all solar radiation values by 1.05 for April through October and 1.08 for the rest of the year.

The corrected values for clear day solar radiation are useful for predicting the maximum solar energy output from a solar heating system. For passive solar designs, the clear day values allow an estimation of the overheating tendency. For greenhouses, the clear day values are useful for calculating maximum ventilation loads.

# ASHRAE CLEAR DAY TABLES

48 Degrees North Latitude

DATE	SOLAR TIME		SOLAR POSITION		BTUH/SQ. FT. TOTAL INSULATION ON SURFACES					BTUH/SQ. FT. TOTAL INSULATION ON SURFACES				
	AM	PM	ALT	AZM	NORMAL	HORIZ.	38	48	58	NORMAL	HORIZ.	38	48	58
JAN 21	8	4	3.5	54.6	37	4	17	19	21	43	10	5	5	4
	9	3	11.0	42.6	185	46	120	132	140	156	62	28	18	16
	10	2	16.9	29.4	239	83	190	206	216	211	118	89	75	59
	11	1	20.7	15.1	261	107	231	249	260	240	171	154	140	121
	12		22.0	0.0	267	115	246	264	275	256	215	214	199	178
					1710	596	1360	1478	1550	266	250	261	246	224
					12					271	272	291	276	253
										272	279	301	286	232
										3158	2474	2386	2200	1974
										99	28	14	10	9
										190	85	75	67	58
										232	141	145	137	125
FEB 21	8	4	11.6	60.5	188	49	95	102	105	190	85	75	67	58
	9	3	19.7	47.7	251	100	178	187	191	232	141	145	137	125
	10	2	26.2	33.3	278	139	240	251	255	254	189	210	201	187
	11	1	30.5	17.2	290	165	278	290	294	266	225	260	252	237
	12		32.0	0.0	293	193	291	304	307	274	256	293	285	268
					2350	1080	1880	1972	2024	272	279	301	286	232
										272	279	301	286	232
										2898	2086	2300	2200	2046
										131	35	44	44	43
										215	92	124	124	121
										251	142	146	197	193
										269	181	251	254	248
MAR 21	8	4	19.5	66.8	270	147	205	207	203	278	205	287	289	284
	9	3	28.2	53.4	287	187	263	266	261	278	205	287	289	284
	10	2	35.4	37.8	295	212	300	303	297	274	205	287	289	284
	11	1	40.3	19.8	298	220	312	315	309	274	205	287	289	284
	12		42.0	0.0	298	220	312	315	309	274	205	287	289	284
					2780	1578	2208	2228	2182	278	205	287	289	284
										131	35	44	44	43
										215	92	124	124	121
										251	142	146	197	193
										269	181	251	254	248
										278	205	287	289	284
										280	213	299	302	296
APR 21	8	4	8.6	97.8	108	27	13	9	8	280	213	299	302	296
	9	3	18.6	86.7	205	85	76	69	59	258	152	2102	2118	2070
	10	2	28.5	74.9	247	142	149	141	129	4	0	1	1	1
	11	1	37.8	61.2	268	191	216	208	194	165	44	86	91	95
	12		45.8	44.6	280	228	268	260	245	179	46	117	129	137
			51.5	24.0	286	252	301	294	278	233	83	186	202	215
			53.6	0.0	288	260	313	305	289	262	133	228	239	242
					3076	2106	2358	2266	2114	274	157	266	277	281
										278	166	279	291	294
										2154	1022	1774	1860	1890
										36	5	17	19	21
										179	46	117	129	137
										233	83	186	202	215
MAY 21	8	4	5.2	114.3	162	61	27	16	15	255	107	227	245	255
	9	3	14.7	103.7	219	118	89	75	60	261	115	241	259	270
	10	2	24.6	93.0	248	171	156	142	123	261	115	241	259	270
	11	1	34.7	81.6	264	217	217	202	182	261	115	241	259	270
	12		44.3	68.3	274	252	265	251	229	261	115	241	259	270
			53.0	51.3	279	274	296	281	258	261	115	241	259	270
			59.5	28.6	280	281	306	292	269	261	115	241	259	270
			62.0	0.0	3254	2482	2418	2234	2010	1668	596	1336	1448	1544
										140	27	87	98	105
										214	63	164	180	192
										242	86	207	226	239
										250	94	222	241	254
										1444	446	1136	1250	1364
JUN 21	8	4	7.9	116.5	172	74	33	19	18	1678	982	1728	1728	1644
	9	3	17.2	106.2	220	129	93	77	59	1678	982	1728	1728	1644
	10	2	27.0	95.8	246	181	157	140	119	1678	982	1728	1728	1644
	11	1	37.1	84.6	261	225	216	198	175	1678	982	1728	1728	1644
	12		46.9	71.6	269	259	262	244	220	1678	982	1728	1728	1644
			55.8	54.8	274	280	291	273	248	1678	982	1728	1728	1644
			62.7	31.2	275	287	301	283	258	1678	982	1728	1728	1644
			65.5	0.0	3312	2626	2420	2204	1950	1678	982	1728	1728	1644
										140	27	87	98	105
										214	63	164	180	192
										242	86	207	226	239
										250	94	222	241	254
										1444	446	1136	1250	1364

Note: To make these values correspond to the ASHRAE clear day model used in this Manual, multiply by a clearness factor of 1.05 for April through October, and 1.08 for the rest of the year.

CREDIT:

## 4.7 Other Design Resources

The simplified performance estimation calculations given in this manual should be accurate enough to evaluate the feasibility of alternate designs. If greater accuracy is needed, for example on large projects, the designer should work through the more detailed standard solar design methods. For designing active solar heating systems, the f-chart design method developed at the University of Wisconsin is widely used. For designing passive solar heating systems, the SLR method developed at Los Alamos Scientific Laboratory is widely used. There are dozens of other design methods described in the technical literature that may be used.

Many of the popular design methods have been implemented on personal computers. These programs can quickly work out the results of a variety of design options and provide graphs and tables of the results. You can find advertisements for these programs in monthly solar energy or personal computing periodicals such as **Solar Age**, **Solar Engineering**, **Byte**, etc. For more assistance you can contact the Montana Department of Natural Resources and Conservation in Helena, MT or the Solar Energy Research Institute in Golden, CO.

Manufacturers of solar equipment usually provide some type of design support to help the user select properly sized components. Lists of manufacturers are available through government sources, trade journals, and solar energy books available at most local bookstores and libraries.

The design services of local engineers, architects, and heating contractors may be used. Names and addresses can be obtained through the appropriate professional organization, trade organizations, DNRC, or the Yellow Pages of the phone book. If you enlist the design services of consultants and manufacturers (especially those outside Montana) you should make them aware of the information in the Montana Solar Data Manual.

Thousands of solar-heated homes have been built during the past ten years. Some of these homes have been instrumented for measuring their comfort and efficiency and these data are available in reports from government agencies. The serious solar designer thus has an expanding resource base of practical examples and data against which he can measure and improve his ideas. This section began with a quote and ends with another.

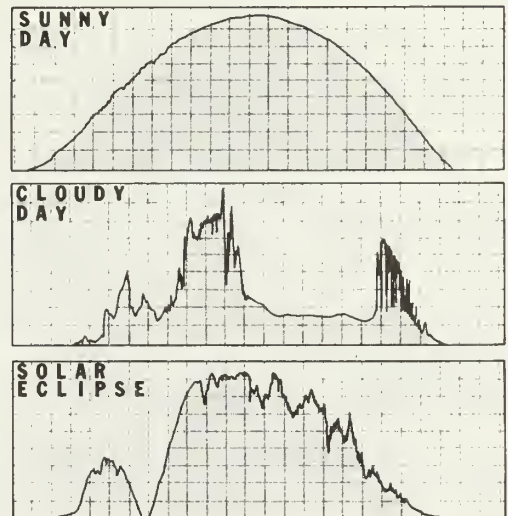
*"A little learning is a dangerous thing:  
Drink deep, or taste not the Pierian spring:  
Where shallow draughts intoxicate the brain,  
And drinking largely sobers us again."*

*Alexander Pope*

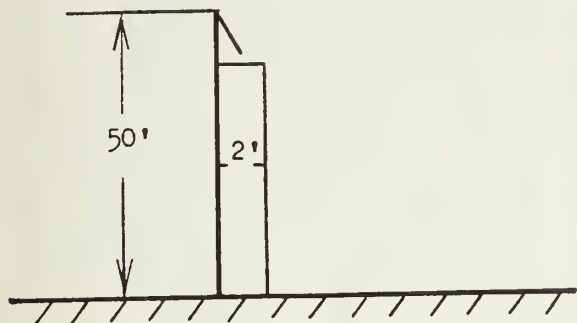
# APPENDIX 1

## SOURCE DATA, SITE DOCUMENTATION

NOTE: Sample site documentation shown for Great Falls, Montana. For documentation of other sites refer to Montana Solar Data Archive Document.





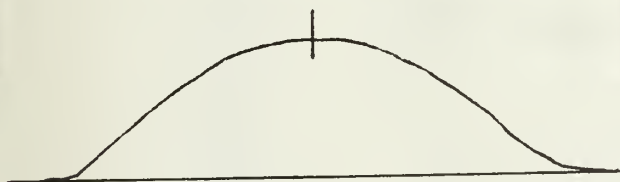


**TRANSDUCER MOUNTING SKETCH**



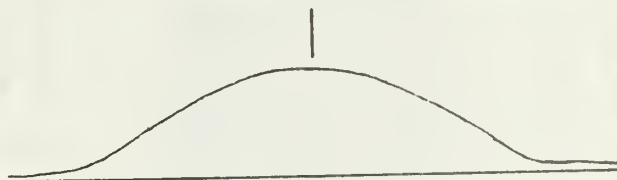
**TRANSDUCER MOUNTING PHOTO**

3/14



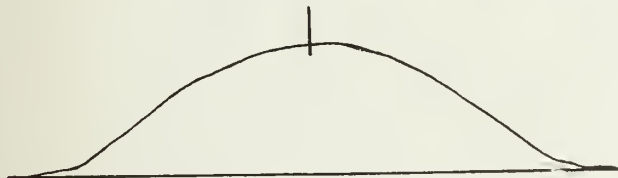
**Spring**

6/24



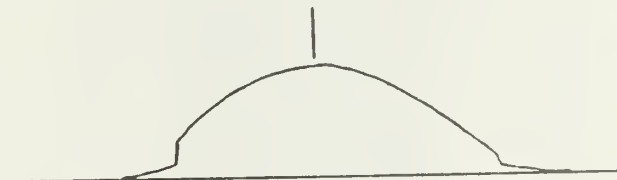
**Summer**

9/18



**Fall**

12/22



**Winter**

**CLEAR DAY CURVES SHOWING TRANSDUCER SHADING**

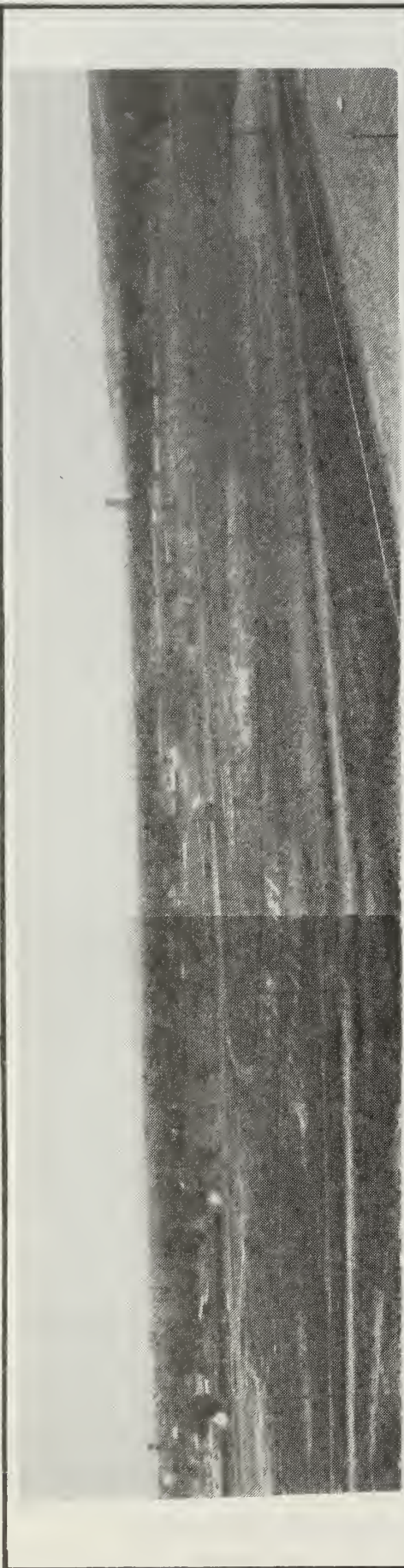
**NOTES:**

**STATION:** Great Falls

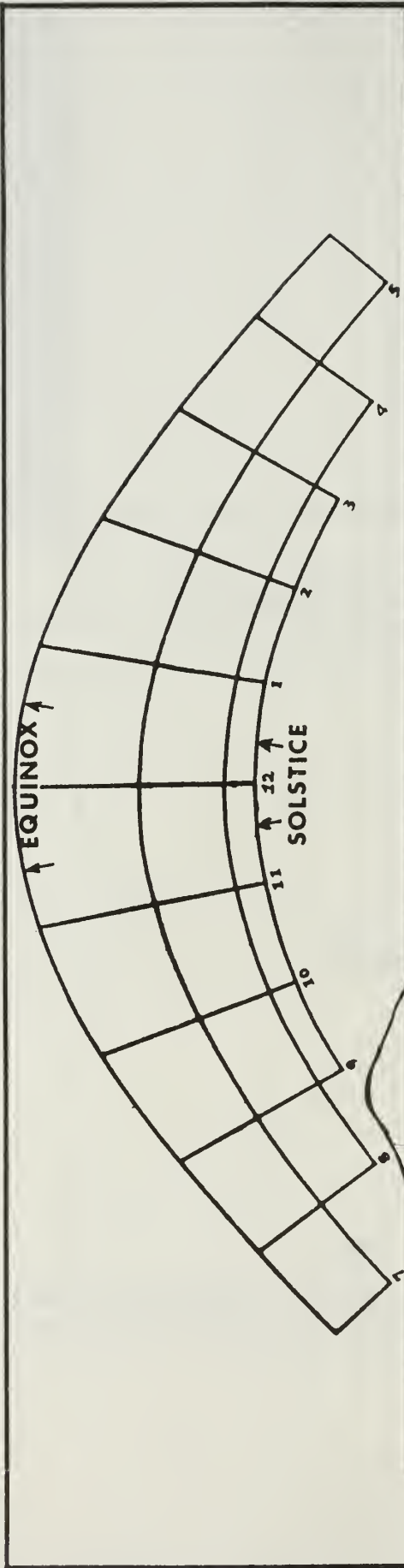
**DATE:** January 1977 - August 1983

**DNRC/ BPA SOLAR DOCUMENTATION**

**FOWLKES ENGINEERING**



PHOTOGRAPH LOOKING SOUTH FROM TRANSDUCER LOCATION



SHADING DIAGRAM FOR TRANSDUCER LOCATION

NOTES:

STATION: Great Falls

DATE: January 1977 - August 1983

DNRC/ BPA SOLAR DOCUMENTATION

FOWLKES ENGINEERING

## STATION MAINTENANCE LOG

[illegible]

**NOTES:**

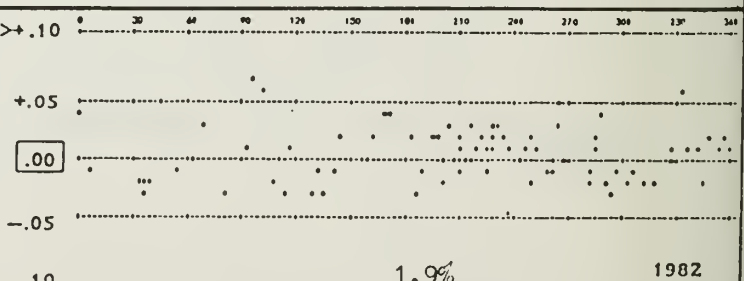
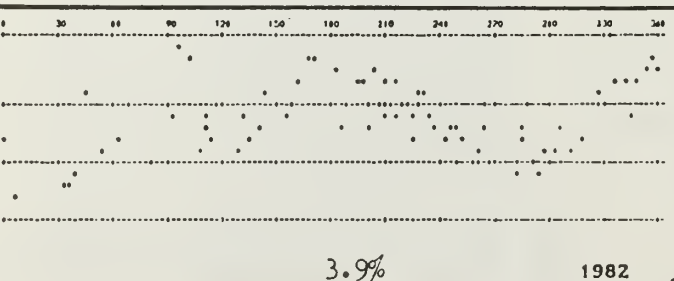
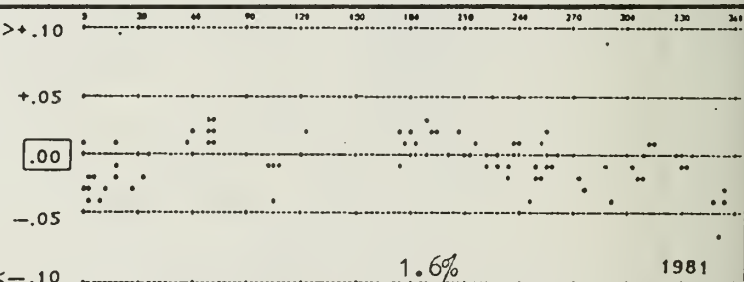
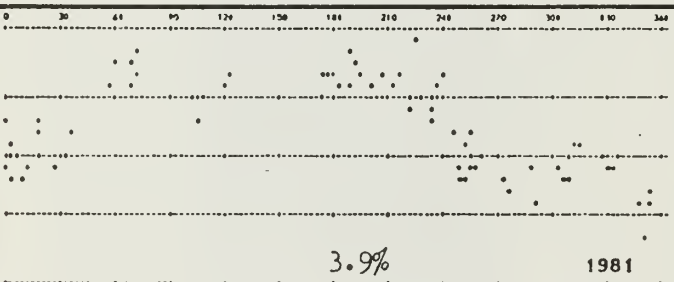
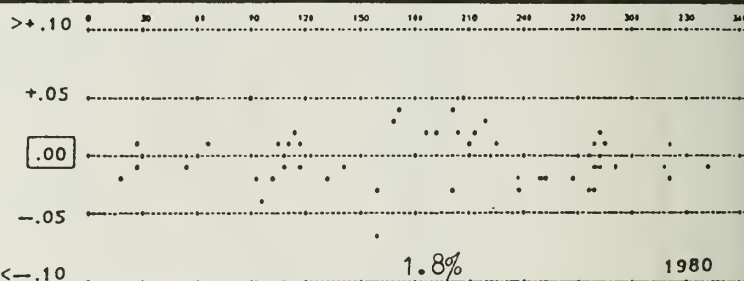
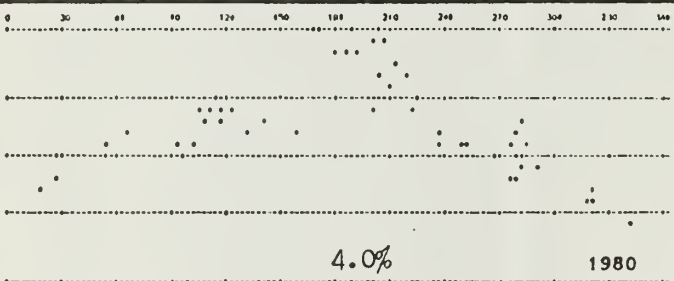
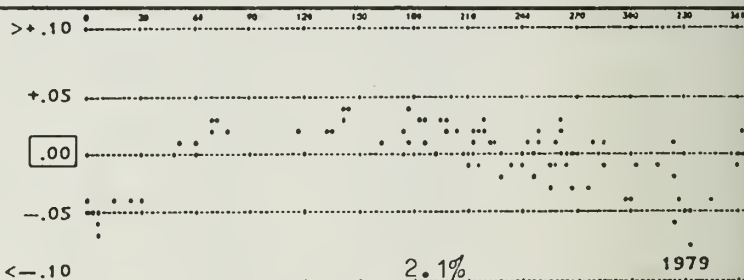
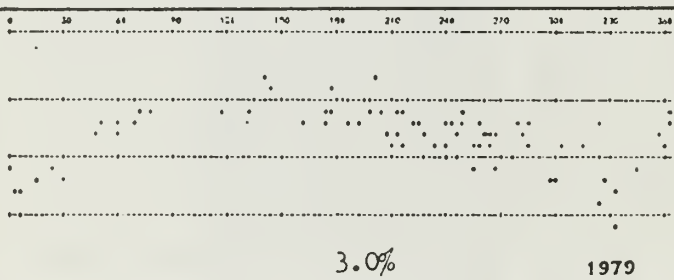
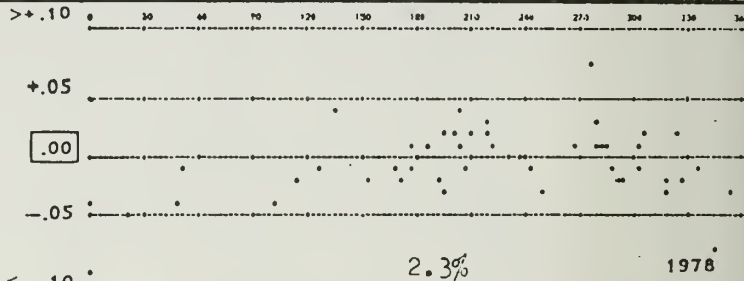
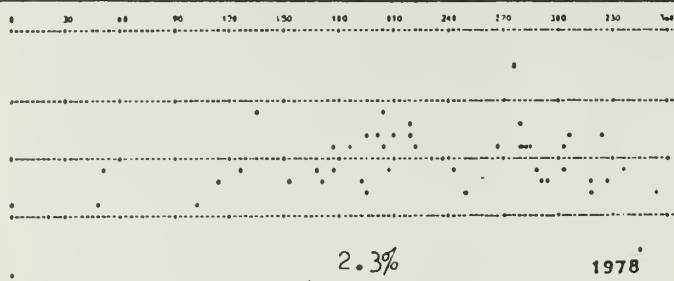
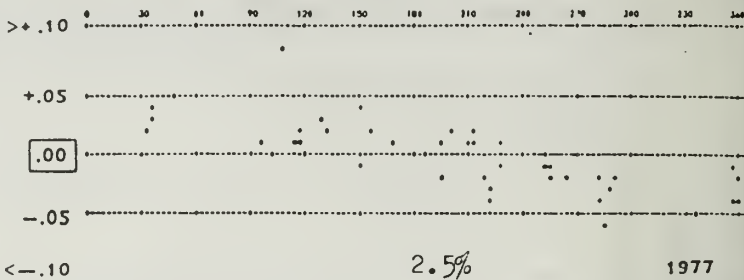
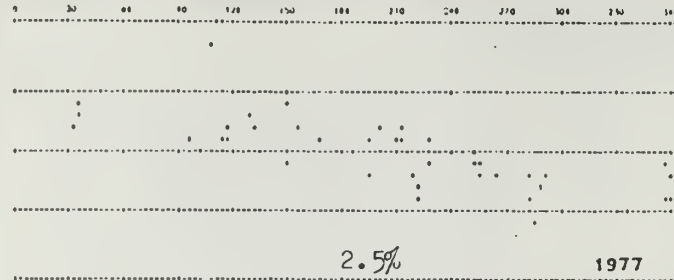
**STATION:** Great Falls

**DATE:** January 1977 - August 1983

**DNRC/ BPA SOLAR DOCUMENTATION****FOWLKES ENGINEERING**

# BEFORE ADJUSTMENT

# AFTER ADJUSTMENT



CLEAR NOON DEVIATION GRAPHS  
CALC - MEASURED/CALC

STATION:  
Great Falls

DNRC/ BPA SOLAR DOCUMENTATION  
FOWLKES ENGINEERING



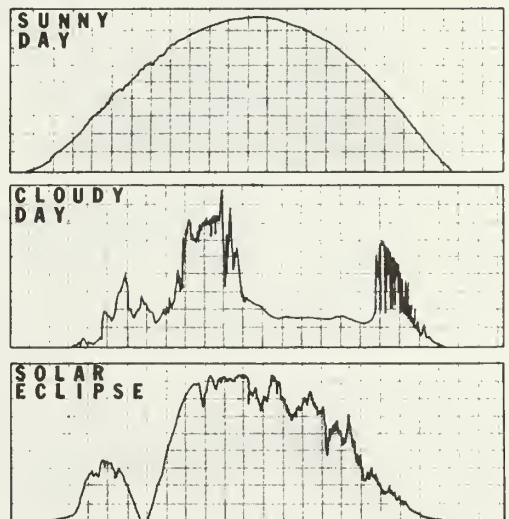


# APPENDIX 2

## ACCURACY OF SOLAR DATA

Reprint of a technical paper published in:

PROCEEDINGS OF THE SIXTH NATIONAL PASSIVE SOLAR CONFERENCE, American Section, International Solar Energy Society, 205B McDowell Hall, University of Delaware, Newark, DE 19711





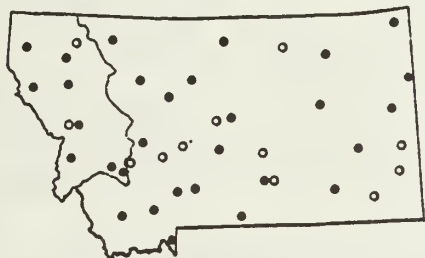


CONTROLLING THE ACCURACY OF SOLAR RADIATION DATA  
FROM A LOW COST, 30 STATION NETWORK

Charles W. Fowlkes, Ph. D., P.E.  
Fowlkes Engineering  
31 Gardner Park Drive  
Bozeman, MT 59715

**ABSTRACT**

For the past four years in Montana we have operated a network of 30 low-cost solar radiation measuring instruments (1). At this point the data base consists of over 40,000 data days. The basic element of data stored on the computer is the half-hour average, radiant intensity on a 60° tilted surface. The sensors are silicon cells mounted on a flat plate and connected to a strip chart recorder. The cost of each instrument at the beginning of the SIMM program was about \$200.



- Continuous Data Recording Station
- Manual Data Station

Fig. 1. The SIMM Network (Solar Insolation Measurement Montana)

Maintaining the accuracy and continuity of experimental data is a difficult task due to the large number and state-wide distribution of the sites (Fig. 1). To visit all 30 instrumented sites requires travelling over 3,000 miles. Since the instruments are home-made, their performance must be carefully and scientifically documented to relate the radiation data to accepted calibration standards. The content of this paper relates our approach to these tasks. Specifically, the results of (a) NOAA calibrations, (b) side-by-side pyranometer comparisons, (c) clear day theoretical comparisons and (d) comparison with independent measurements from the National Solar Data Network are discussed. The results of each approach in assessing accuracy and maintaining data integrity of the SIMM instruments is discussed.

**1. INTRODUCTION**

The instruments are mounted on public high schools throughout Montana. This program uses volunteers, typically high school teachers, who help maintain the instruments in the field. The strip chart records are mailed by the volunteers to our office where they are traced on a digitizer for input into a microcomputer.

The output of our solar measurement program is published annually in the Montana Solar

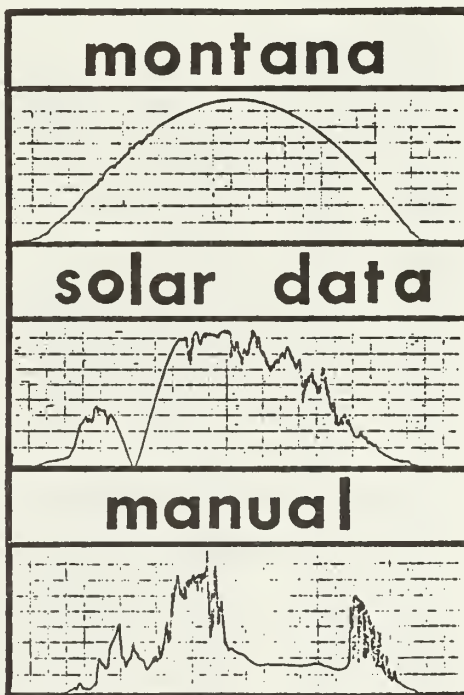


Fig. 2. Cover of Montana Solar Data Manual, illustrating insolation records (including eclipse on 2/26/79)

Data Manual (2). This manual addresses an audience that ranges from technical and professional people to individual homeowners, backyard inventors and solar enthusiasts. The manual reports insolation data and cloudy day statistics. Climatological data, solar design methods and a selected bibliography are also included in the manual. The manual is distributed free by the sponsoring agency, Alternative Renewable Energy Sources Program, Montana Department of Natural Resources and Conservation. About 500 copies of the manual have been distributed to libraries, universities and designers. Another 500 copies of a revised and updated manual are being prepared for distribution during the summer of 1981. The SIMM network is in its fifth year.

## 2. DATA REDUCTION ERROR

Strip chart data is processed by tracing the curves on a digitizer platen connected to a microcomputer. The resolution of the platen is 0.1 mm and each curve is represented by 200 to 400 coordinates. The reading error due to resolution is less than 1%. The primary source of data reduction error is the repeatability of the curve tracing itself. Reproducibility tests have been run on over 1,000 data days. The reproducibility of the monthly average insolation is always  $\pm 2\%$  and often within 1%.

## 3. TRANSDUCER ERRORS

The SIMM silicon cell transducer is covered by a glass plate potted in silicone sealant. Tilt calibration tests have shown that the output of the SIMM transducer falls off at large angles of incidence. This is due primarily to the glass cover plate and is normally termed "cosine error".

The measured cosine response of the SIMM transducer was input into a computer simulation model to predict the effect of this error on the daily total insolation throughout the year (Table 1). Experimental data presented later in this report indicates that the summer errors are less than those predicted by the model.

TABLE 1.  
CALCULATED EFFECT OF COSINE ERROR (%)

MONTH	CLEAR DAY	AVERAGE DAY
DEC	-2	-2
JAN NOV	-3	-2
FEB OCT	-4	-3
MAR SEP	-4	-3
APR AUG	-6	-4
MAY JUL	-8	-5
JUN	-8	-5

## 4. CLEAR DAY METHOD

All SIMM transducers are calibrated before installation. The reference instruments have included Kipp pyranometers, Li-Cor radiometers and a NOAA calibrated SIMM transducer. To allow for drift and aging, which may occur while the instrument is on site, we make use of a clear day correction technique similar to the methods used to correct the SOLMET data base.

The essence of our clear day procedure is to compare the measured noon flux to a value predicted by a theoretical clear day model. We have used the ASHRAE model and a model provided by Douglas Hoyt of NOAA (3). As part of our data reduction procedure we pick off the noon maximum on all clear days and compute a theoretical value for that same day. If there is a consistent difference of more than a few percent, the experimental data for that period is all scaled to match the theoretical value. Figure 3 shows a graph of experimental and theoretical clear day values for two stations for 1978.

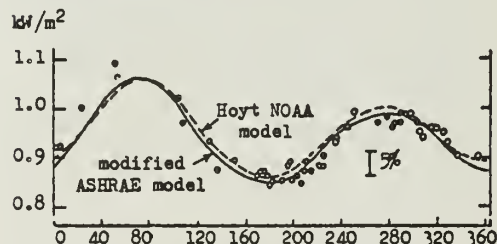


Fig.3a. Great Falls data for 1978 showing two clear-day models with data

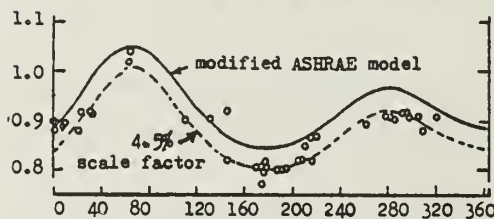


Fig.3b. Glendive data for 1978 illustrating use of scale factor

Experimental clear day maximums from an Eppley PSP (used in the National Solar Data Network) are compared to the theoretical Hoyt values in Table 2. The measured maximums fluctuate about the theoretical maximum. This could be due to fluctuations in the atmosphere and errors due to temperature effects, calibration and dirt on the instrument. The absolute value of this fluctua-

tion for 1980 in Billings, MT average 2.3%. SIMM data are typically matched to the Hoyt model to within 3% annual average deviation (1, 2). This data thus supports the clear day method used in the SIMM network.

TABLE 2.  
CLEAR DAY, NOON MAX, ( $\text{kWh-m}^2$ ), BILLINGS 1980

DAY	HOYT NOAA	NSDN (PSP)	FOWLKES (SIMM)
6	0.92	0.98	0.98
19	0.95	0.96	1.00
20	0.95	1.01	1.01
28	0.98	1.07	1.01
29	0.98	1.17	1.00
54	1.06	1.04	1.01
55	1.06	1.07	1.07
86	1.08	1.07	1.05
95	1.05	1.03	1.03
97	1.05	1.05	1.00
104	1.02	1.02	1.00
105	1.02	0.97	0.98
107	1.01	1.00	1.01
108	1.01	1.00	0.99
111	1.00	0.96	0.99
117	0.98	0.95	0.98
118	0.97	0.93	0.95
127	0.94	0.90	0.92
128	0.94	0.92	0.94
142	0.89	0.84	0.90
143	0.89	0.86	0.90
145	0.88	0.86	0.92
161	0.86	0.84	0.83
165	0.85	0.83	0.85
174	0.85	0.82	0.83
177	0.85	0.84	0.83
178	0.85	0.84	0.84
179	0.85	0.86	0.85
180	0.85	0.86	0.87

##### 5. NATIONAL SOLAR DATA NETWORK COMPARISON

The Billings Shipping solar system in Billings, Montana was instrumented three years ago for performance monitoring as part of The National Solar Data Network (NSDN). Global insolation is measured here by an Eppler PSP pyranometer tilted at  $50^\circ$ . Daily totals and maximums are reported each month in Environmental Data for Sites in the National Solar Data Network (4).

During 1980 there were 337 days of simultaneous data from both the NSDN (Eppler PSP) and the SIMM transducer at Billings High School. The NSDN  $50^\circ$  tilt data was converted to a  $60^\circ$  tilt using the ratio of ASHRAE clear day totals. This simplified method would tend to over-correct the NSDN data by a few percent in the summer. Since the correction itself averages only about  $\pm 3\%$ , the error introduced is not large (5).

A scatter plot of daily total insolation for SIMM vs. NSDN for 1980 is shown in Figure 4. For 337 common data days, the linear correlation coefficient was 0.990. There are about

a dozen points that are scattered. These discrepancies probably occurred on days when

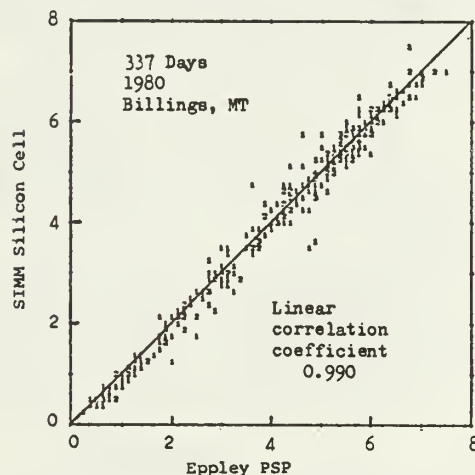


Fig. 4. Scatter plot, daily totals,  $\text{kWh-m}^2$

TABLE 3.  
DAILY TOTALS, ( $\text{kWh-m}^2$ ), BILLINGS, NOV. 1980

DAY	NSDN (PSP)	FOWLKES SIMM	NSDN LESS SIMM
1	2.59	2.66	-.07
2	2.18	2.13	.05
3	5.70	5.72	-.02
4	1.92	1.59	.33
5	6.07	6.16	-.09
6	1.51	1.25	.26
7	1.06	1.00	.06
8	4.41	4.78	-.37
9	1.06	1.06	.00
10	2.42	2.47	-.05
11	1.23	1.19	.04
12	0.65	0.63	.02
13	0.87	0.47	.40
14	5.27	5.06	.21
15	5.80	5.91	-.11
16	5.74	5.84	-.11
17	5.87	5.81	.06
18	2.92	2.84	.08
19	1.65	1.41	.25
20	3.76	3.84	-.08
21	1.82	1.84	-.03
22	0.58	0.50	.08
23	5.75	5.63	.13
24	2.28	2.22	.06
25	0.85	0.53	.31
26	5.17	4.63	.55
27	0.94	0.81	.13
28	5.80	5.31	.48
29	1.82	1.72	.11
30	0.39	0.38	.02
AVG	2.94	2.85	3.07%

snow or frost covered one transducer part of that day. Neither instrument is regularly cleaned or cleared of snow. The remaining scatter is primarily due to differences in spectral response, calibration error, cosine response and temperature coefficients (annual temperature extreme span over 70° C).

The daily totals for the month of November, 1980 are shown in Table 3. The daily average insolation for November for the SIMM instrument is 3.07% less than the NSIN instrument. This difference closely corresponds to the -3% error predicted for this month due to the low cosine response of the SIMM transducer.

The average daily totals for each instrument are shown for each month in 1980 in Table 4. The SIMM instrument is normally lower by a few percent, which is probably due to cosine error. (The December average is faulted because the SIMM instrument was not recording data during a week with several clear days.)

TABLE 4.  
MONTHLY AVERAGE DAILY TOTAL ( $\text{kWh-m}^{-2}$ )

MONTH	NSIN (PSP)	FOWLKES SIMM
JAN	3.13	3.29
FEB	3.29	3.29
MAR	4.14	4.01
APR	5.23	5.18
MAY	4.77	4.74
JUN	4.84	4.82
JUL	5.25	5.15
AUG	4.75	4.73
SEP	4.80	4.72
OCT	*4.38	4.33
NOV	2.94	2.85
DEC	2.05	*1.88

\*missing 8 to 10 days

#### 6. SIDE BY SIDE COMPARISONS

Side by side comparisons were run for eight months during the winter of 1980 and spring of 1981 to compare (a) a Kipp pyranometer, (b) a Li-Cor 200S silicon cell radiometer, and (c) the SIMM silicon cell radiometer. All transducers were mounted at 0° azimuth and 60° tilt and connected to a microcomputer based data acquisition system (DAS). The DAS had a resolution of 12 bits, an accuracy of better than  $\pm 0.5\%$ ; each transducer and the ambient air temperature were sampled once each second. These readings were averaged over 10 minute intervals and the average data stored on magnetic tape. This data base consists of  $15 \times 10^6$  side by side readings of each transducer.

Table 5 shows a typical portion of this data base condensed into daily total insolation. The Kipp pyranometer was recalibrated at the NOAA facility in 1979 and this calibration factor was used. The factory calibration supplied for the Li-Cor was used and the SIMM transducer was calibrated to the Kipp on a clear day near solar noon according to our standard procedure. No correction was made for ambient temperature, which varied between -18° C and +17° C during this period. The monthly totals of the Kipp and the Li-Cor agree to within  $\pm 1\%$  while the SIMM transducer is 3% below the Kipp. This lower reading agrees with the predictions of the cosine error model discussed previously (Table 1).

TABLE 5.  
BOZEMAN DAILY TOTALS ( $\text{kWh-m}^{-2}$ )  
NOVEMBER, 1980

DAY	KIPP	LI-COR	SIMM
1	2.80	2.84	2.72
2	1.95	1.94	1.88
3	1.01	0.99	0.93
4	2.04	2.07	1.96
7	0.42	0.44	0.39
8	4.21	4.22	4.13
9	1.39	1.39	1.31
10	1.40	1.32	1.30
11	0.54	0.55	0.53
12	1.14	1.15	1.12
13	5.67	5.62	5.44
14	*5.33	6.60	6.36
15	6.68	6.55	6.38
16	6.62	6.61	6.43
17	4.13	4.40	4.24
18	1.10	1.03	1.05
19	0.93	0.89	0.86
20	3.83	3.77	3.68
21	3.04	3.02	3.00
22	0.73	0.68	0.66
23	5.43	5.40	5.28
24	3.71	3.61	3.54
25	0.71	0.64	0.63
26	4.44	4.43	4.28
27	1.74	1.66	1.66
29	2.01	1.94	1.93
30	1.54	1.45	1.44
AVG	2.66	2.64	2.57

\*Frost

The instantaneous readings of the three transducers during mid-day in clear weather were always within a  $\pm 5\%$  band and often were within  $\pm 1\%$ . The Kipp and the Li-Cor were typically within  $\pm 0.01 \text{ kWh-m}^{-2}$  for the entire day, while the SIMM transducer's output would typically be  $0.05 \text{ kWh-m}^{-2}$  low in early morning and late afternoon (the cosine error).

## 7. SIMM NETWORK RELIABILITY

Each summer a technician visits all 30 stations to check the transducer mounting and the condition of the wiring and the strip chart recorder. If the system breaks down during this year the recorder and/or transducer are sent to us by the volunteer. We repair or replace the unit, test it, and send it back.

During the period between January, 1977 and December, 1980, there were 38,956 possible station data-days. We recorded 32,425 data-days, or 83% of the total. The 17% lost data was primarily due to recorders running out of paper (mostly during the summer months). During four years of operation two recorders were stolen, two transducers were vandalized, six motors burned out and there were about two dozen instances of miscellaneous mechanical or electrical failure. Data was lost several times when wires were cut or power was turned off during remodeling work at the school. Some data has been lost in the mail and in two instances strip charts were destroyed by a janitor's floor polisher. Some suspicious data has been rejected after arriving at the offices.

## 8. CONCLUSIONS

- The clear day correction method provides an economical way to maintain the calibration of the network. Current comparison data indicated that this correction puts the data into a  $\pm 5\%$  accuracy band.
- The data recovery of 83% would be difficult to improve in this volunteer operated network. Missing data is not too important due to the high density of the 30 measuring stations.
- Extensive comparison data shows that errors due to spectral and temperature effects are well within the  $\pm 5\%$  error band. The most serious fault with the SIMM transducer is the poor cosine response which produces a systematic error of about  $-3\%$  during the heating season.
- This data base has been made available to the public along with supplementary material in an effort to improve the quality of solar design in Montana.
- Measuring insolation on a  $60^\circ$  tilted surface reduces the net error in the data when used for solar design.

## 9. ACKNOWLEDGEMENTS

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of Natural Resources and Conservation. This program derives funds from a severance tax on coal mined in Montana. The support and advice of John Orndorff, Jeannis Thurston and Georgia Brensdal are acknowledged. The assistance of the volunteers at the measurement stations is crucial to the success of this program and their contributions are gratefully acknowledged.

Several members of the staff at Fowlkes Engineering have contributed to this solar measurement program and this paper. Sharon Kleingartner and Pat Sullivan have carefully logged and organized strip chart records for over 40,000 data-days. Sharon is acknowledged for her important role in entering the data into the computer for processing. Carlos Lozano has contributed to this paper by writing numerous computer programs to analyze the data. Jody Martinson typed this paper and made editorial corrections.

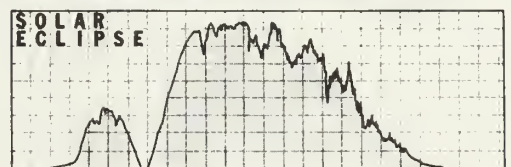
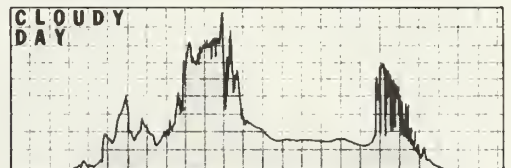
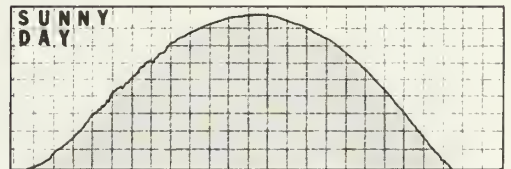
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- (2) Fowlkes, Charles W., Montana Solar Data Manual, available from Montana Department of Natural Resources & Conservation, Alternative Renewable Energy Sources Program, 32 South Ewing, Helena, MT 59620 (1979).
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- (4) Environmental Data for Sites in the National Solar Data Network (monthly), DOE, NATIONAL SOLAR DATA PROGRAM, Solar/0010-80.
- (5) ASHRAE HANDBOOK OF FUNDAMENTALS, New York: American Society of Heating, Refrigerating and Air-Conditioning Engineers (1972).



# APPENDIX 3

## LIST OF SITE VOLUNTEERS, 1977-1982





The following volunteers maintained the continuous solar recorders at the thirty sites listed in this publication.

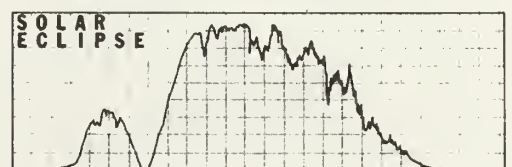
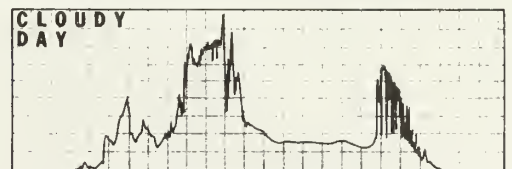
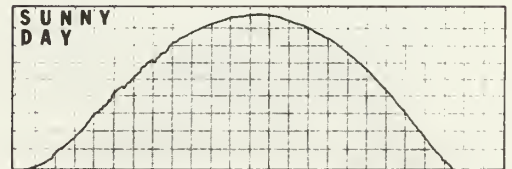
<b>Location</b>	<b>School</b>	<b>Volunteer</b>	<b>Year</b>
Anaconda	Anaconda H.S.	Mike Knutson	1979-82
		Tom Facey	1978-79
Billings	Billings Sr. H.S.	Mike Jablin	1977-82
Bozeman	Bozeman Sr. H.S.	Roscoe Montgomery	1977-82
Browning	Browning H.S.	Mr. Marion Salway	1981-82
		Jim Prestbo	1977-81
Butte	Butte H.S.	John Giop	1978-82
Choteau	Choteau H.S.	Norman Kamrud	1978-82
Colstrip	Colstrip H.S.	Kelly Taylor	1979-82
		Dave Bowser	1977-79
Dillon	Beaverhead Co. H.S.	William Mular	1977-82
Ennis	Madison Val. Cons. H.S.	Jay Willett	1979-82
		Orville Hess	1978-79
Fort Benton	Fort Benton H.S.	A. Wm. Kindzerski	1979-82
		T. Daniel Gillen	1978-79
Glasgow	Glasgow H.S.	Norman Girard	1977-82
Glendive	Dawson Co. H.S.	Richard Lindgren	1978-82
Great Falls	C.M. Russell H.S.	W. Gary Sheldon	1977-82
Hamilton	Hamilton H.S.	William Delaney	1977-82
Harlowton	Harlowton H.S.	Scott Dubbs	1980-82
		Milo Coladonato	1978-80
Havre	Havre H.S.	Marvin Gunnarson	1979-82
		Avon Whitehead	1977-79
Helena	Helena H.S.	Jim Haslip	1977-82
Jordan	Garfield Co. H.S.	Michael G. Mansfield	1979-82
Kalispell	Flathead H.S.	Gary Freebury	1977-82
Lewistown	Fergus H.S.	Howard Cooper	1977-82
Libby	Libby H.S.	Mike Funk	1977-82
Livingston	Park Sr. H.S.	Ben Williams	1978-82
Miles City	Custer Co. H.S.	Otto Neuhardt	1977-82
		John Potts	1977-82
Missoula	Hellgate H.S.	Norman Jacobson	1977-82
Plentywood	Plentywood H.S.	Harold Gackle	1978-82
Polson	Polson H.S.	Dan O'Brien	1979-82
		Ted Macy	1977-79
Red Lodge	Red Lodge H.S.	Bob Holmen	1978-82
Sidney	Sidney Sr. H.S.	Dan Scow	1980-82
		Gene Krueger	1978-80
Thompson Falls	Thompson Falls	Stuart Kilgore	1980-81
		Walter Clark	1978-79
West Yellowstone	West Yellowstone H.S.	Scott Carsley	1978-81
		Wolf Kuestner	1981-82

Many high school students also took manual solar recordings. This information was used to cross-check the continuous recordings.

Location	School	Volunteer	Year
Baker	Baker H.S.	Max Mueller	1978-82
Big Timber	Sweetgrass Co. H.S.	Dick Willems	1977-78
Billings	Billings West H.S.	Gerald Raab	1978-82
Boulder	Jefferson H.S.	Mike Myrhow	1978-82
Broadus	Powder River Co. H.S.	Henry Eslinger	1977-81
Chester	Chester H.S.	Marvin Krook	1977-80
Chinook	Chinook H.S.	Gail Swant	1977-78
Circle	Circle H.S.	Robert Fitzgerald	1977-79
Columbus	Columbus H.S.	Waymoth Fitzgerald Jr.	1977-78
Conrad	Conrad H.S.	James Guthrie	1978-80
Culbertson	Culbertson H.S.	Larry Hyslop	1978-79
Deer Lodge	Powell Co. H.S.	Gary Swant	1977-80
Ekalaka	Carter Co. H.S.	Pat Vaskey	1979-82
		Jane Frye	1977-79
Eureka	Lincoln Co. H.S.	Neil W. Nelson	1979-80
		C.W. Calvert	1979
Forsyth	Forsyth H.S.	Eli Urbaniak	1978-79
Great Falls	East Jr. H.S.	John Chase	1979
Hardin	Hardin H.S.	Bonnie Pluhar	1978
		Roland Croghan	1977-78
Harlem	Harlem H.S.	G. Daniel McNeill	1978-79
Hobson	Hobson H.S.	Rick McIntyre	1977-82
Malta	Malta H.S.	Steve Schumacher	1978-82
		Jeffrey Bredeson	1977-78
Missoula	Sentinel H.S.	Lyle Leischner	1979-82
		Ronald Perrin	1978-79
Roundup	Roundup H.S.	Jim Schladweiler	1977-81
Scobey	Scobey H.S.	Dee Black	1978-79
Superior	Superior H.S.	Clark Conrow	1977-79
Townsend	Broadwater Co. H.S.	William Alley	1977-82
Whitefish	Whitefish H.S.	Bruce Tannohill	1978-81
White Sulphur Springs	White Sulphur Sp. H.S.	Ken Marks	1978-82
		Connie Perkins	1977-78
Winnett	Winnett H.S.	Frank Witter	1977-78
Wolf Point	Wolf Point H.S.	Arthur Sikkink	1977-82

# APPENDIX 4

## CONVERSION IDENTITIES





**LENGTH m**

1 meter = 3.2808 feet  
 1 meter = 39.3701 inches  
 1 km = 0.62137 miles  
 1 ft/min = 0.00508 m/s  
 1 mile/h = 0.44704 m/s  
 1 km/h = 0.277778 m/s

**TEMPERATURE**

$t^{\circ}\text{F} = (1.8 \times t^{\circ}\text{C}) + 32$   
 $t^{\circ}\text{C} = (t^{\circ}\text{F} - 32)/1.8$

**MASS kg**

1 lb = 0.45359237 kg  
 1 oz = 28.3495 g  
 1 lb/cu ft = 16.0185 kg/cu m  
 1 lb/h = 0.00012599 kg/s

**ENERGY**

1 kWh = 3412.08 Btu  
 1 kWh = 3600 kJ  
 1 Btu =  $2.928 \times 10^{-4}$  kWh  
 1 Btu = 1.0548 kJ  
 1 Btu = 0.251996 kcal  
 1 Btu =  $10^{-5}$  therm  
 1 Btu =  $10^{-15}$  quad

**POWER**

1 kW = 3414.43 Btu/h  
 1 kW = 56.8253 Btu/min  
 1 kW = 238.662 cal/sec  
 1 Btu/h =  $2.931 \times 10^{-4}$  kW  
 1 Btu/h = 0.01667 Btu/min  
 1 Btu/h = 0.0700 cal/sec  
 1 Btu/h =  $3.9275 \times 10^{-4}$  hp

**AREA sq m**

1 sq m = 10.7639 sq ft  
 1 sq m = 1550 sq in  
 1 sq km = 0.3860 sq mi  
 1 sq km = 247.105 acres

**VOLUME cu m**

1 cu ft = 28.3168 liters  
 1 US gal = 3.78544 liters  
 1 cu ft/lb = 0.062428 cu m/kg  
 1 cfm = 0.471947 liter/s  
 1 US gpm = 0.0630907 liter/s

**FORCE newton N**

1 lbf = 4.44822 N  
 1 psi = 6.89476 kPa  
 1 in H<sub>2</sub>O = 249.089 Pa  
 1 atm = 101.325 kPa

**ENERGY DENSITY**

1 kWh/sq m = 316.815 Btu/sq ft  
 1 kWh/sq m = 3600 kJ/sq m  
 1 kWh/sq m = 360 J/c sq m  
 1 kWh/sq m = 85.933 cal/cu cm (langley)  
 1 Btu/sq ft =  $3.1517 \times 10^{-3}$  kWh/sq m  
 1 Btu/sq ft = 11.3538 kJ/sq m  
 1 Btu/sq ft = 1.13538 J/cu cm  
 1 Btu/sq ft = 0.27125 cal/cu cm (langley)

**POWER DENSITY**

1 kW/sq m = 317.21 Btu/sq ft/h  
 1 kW/sq m = 3600 kJ/sq m/h  
 1 kW/sq m = 0.1 W/cu cm  
 1 kW/sq m = 0.23901 langley/sec  
 1 kW/sq m = 14.3406 langley/sec  
 1 Btu/sq ft/h = 3.1524 W/sq m  
 1 Btu/sq ft/h = 11,348 kJ/sq m/h  
 1 Btu/sq ft/h =  $3.1524 \times 10^{-4}$  W/cu cm  
 1 Btu/sq ft/h =  $7.5347 \times 10^{-5}$  langley/sec  
 1 Btu/sq ft/h =  $4.5208 \times 10^{-3}$  langley/min

The following prefixes are recommended  
for use with SI Units:

tera T $10^{12}$ ,	giga G $10^9$
mega M $10^6$ ,	kilo k $10^3$
milli m $10^{-3}$ ,	micro $10^{-6}$
nano n $10^{-9}$ ,	pico p $10^{-12}$

The following prefixes are recommended  
for use with SI Units:

tera T $10^{12}$ ,	giga G $10^9$
mega M $10^6$ ,	kilo k $10^3$
milli m $10^{-3}$ ,	micro $10^{-6}$
nano n $10^{-9}$ ,	pico p $10^{-12}$

## SOME PROPERTIES IN SI UNITS

### Density (kg/m<sup>3</sup>)

Copper	8795
Steel	7850
Aluminum	2675
Glass, standard	2515
Concrete, typical building	2400
Water, 4°C	1000
Ice, -1°C	918
Gypsum plaster, dry, 23°C	881
Oak, 14% wet	770
Pine, 15% wet	570
Pine fiberboard, 24°C	256
Asbestos cement, sheet, 30°C	150
Cork board, dry, 18°C	144
Ebonite, expanded, 10°C	64
Mineral wool, batts, -2°C	32
Polyurethane, foam, rigid	24
Polystyrene, expanded, 10°C	16
Air, p <sub>o</sub> , 20°C	1.204

### Thermal conductivity (W/m°C)

Copper	385
Aluminum	211
Steel	47.6
Ice, -1°C	2.26
Concrete, typical building	1.73
Glass, standard	1.05
Water, 20°C	0.596
Asbestos cement, sheet, 30°C	0.319
Gypsum plaster, dry, 23°C	1.170
Oak, 14% wet	0.160
Pine, 15% wet	0.138
Pine fiberboard, 24°C	0.051
Cork board, dry, 18°C	0.041
Mineral wool, batts, -2°C	0.034
Polystyrene, expanded, 10°C	0.034
Ebonite, expanded, 10°C	0.030
Air, p <sub>o</sub> , 20°C	0.030
Polyurethane, foam, rigid	0.024

### Heat of vaporization (kJ/kg)

Water, 20°C	2454.0
Water, 100°C	2257.0

### Specific heat (kJ/kg°C)

Water, 20°C, p <sub>o</sub>	4.19
Ice, -21°C to -1°C	2.10
Steam (c <sub>p</sub> ), 100°C, p <sub>o</sub>	1.95
Air (c <sub>p</sub> ), 20°C, p <sub>o</sub>	1.012
Concrete, 18°C	0.837
Standard gravity g <sub>o</sub> : g <sub>o</sub> =	9.80665 m/s

### Gas constants:

$$R_u = 8314.4 \text{ J/kmol K universal}$$

$$R_a = 287.045 \text{ J/kg K air}$$

### Stefan-Boltzmann constant:

$$\sigma = 5.6697 \times 10^{-8} \text{ W/cu m K}^4$$





**MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION**

**Energy Division  
Capitol Station  
Helena, MT 59620**

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